ANALYSIS OF FLUID FLOW AND DISTRIBUTION PATTERNS IN A TROUGH TYPE DISTRIBUTOR

By

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NOMENCLATURE

a - width of lateral outlet, ft or m.

$(A_j)_{min}$ - Area of the jet at the minimum cross-sectional area, ft^2 or m^2.

$A_o = \pi d_o^2/4$ - cross sectional area of the orifice, ft^2 or m^2.

A_T - cross section of the stream, ft^2 or m^2.

C_o or C_d - orifice coefficient or discharge coefficient.

C_v - coefficient of variation.

d_o or D_B - orifice diameter, ft or m.

D_p - diameter of packing, ft or m.

g - acceleration due to gravity, ft/s^2 or m/s^2.

h - height of liquid above orifice or head, ft, m.

K - barrier inclination parameter

l - thickness of orifice plate, ft or m.

N - number of holes in the trough.

p - pressure, lb_f/ft^2 or N/m^2.

Q - volumetric flow rate through each orifice, ft^3/s or m^3/s.

Q_r - ratio of outflow through each lateral orifice-weir unit to inflow in main channel.

$R_A = A_T/W_P$ - radius at station A, ft or m.

Re - orifice Reynolds number = $dv_o\rho/\mu$.

T - temperature of the liquid, ^oK.

U_h - gas velocity through hole in sieve tray, ft/s or m/s.

V_2	flow velocity at the downstream edge of a lateral outlet, ft/s or m/s.
V_j	jet velocity, ft/s or m/s.
V_o or v_o or v	velocity through orifice, ft/s or m/s.
W_P	wetted perimeter, ft or m.
X	mole fraction of light key in liquid phase.
Z	elevation, ft or m.
α	kinetic energy correction factor(in orifice coefficient derivation).
α	angle of inclination of the jet.
ρ	density of liquid, lb/ft^3 or kg/m^3.
η	jet velocity ratio, V_1/V_j.
β	NA_o/A_T.
μ	viscosity of liquid, lb/ft-s or kg/m-s.
η	viscosity of the liquid , cp.(when used in correlation for calculating water viscosity).

CHAPTER I

INTRODUCTION

Separation processes form an integral part of the chemical process industries. The profitability of a company is very often dependent on the efficiency of these processes. Distillation, absorption, stripping and extraction are the most frequently used operations in chemical plants. A key to successfully operating these plants is to provide an efficient means of contacting the liquid and vapor streams in these processes. Liquid-vapor contacting is generally carried out in either tray or packed columns. Traditionally, tray columns have been more frequently used in process plants, but packed columns are becoming increasingly popular because of the lower pressure drops and costs associated with them. The main problem with packed columns is their sensitivity to liquid maldistribution. Liquid maldistribution in tray columns, on the other hand, is not a major concern, because distribution irregularities from the upper tray are rectified when the liquid mixes in the downcomer and is redistributed to the lower tray.

Packings and Distributors

Fig 1-1 shows a composite packed column with various associated internals. The performance of the column depends on proper selection and design of these internals. The choice of appropriate packing is important for the efficient operation of the column. A large amount of research has been devoted towards developing and optimizing performance characteristics of packings. One point that must be emphasized is that the

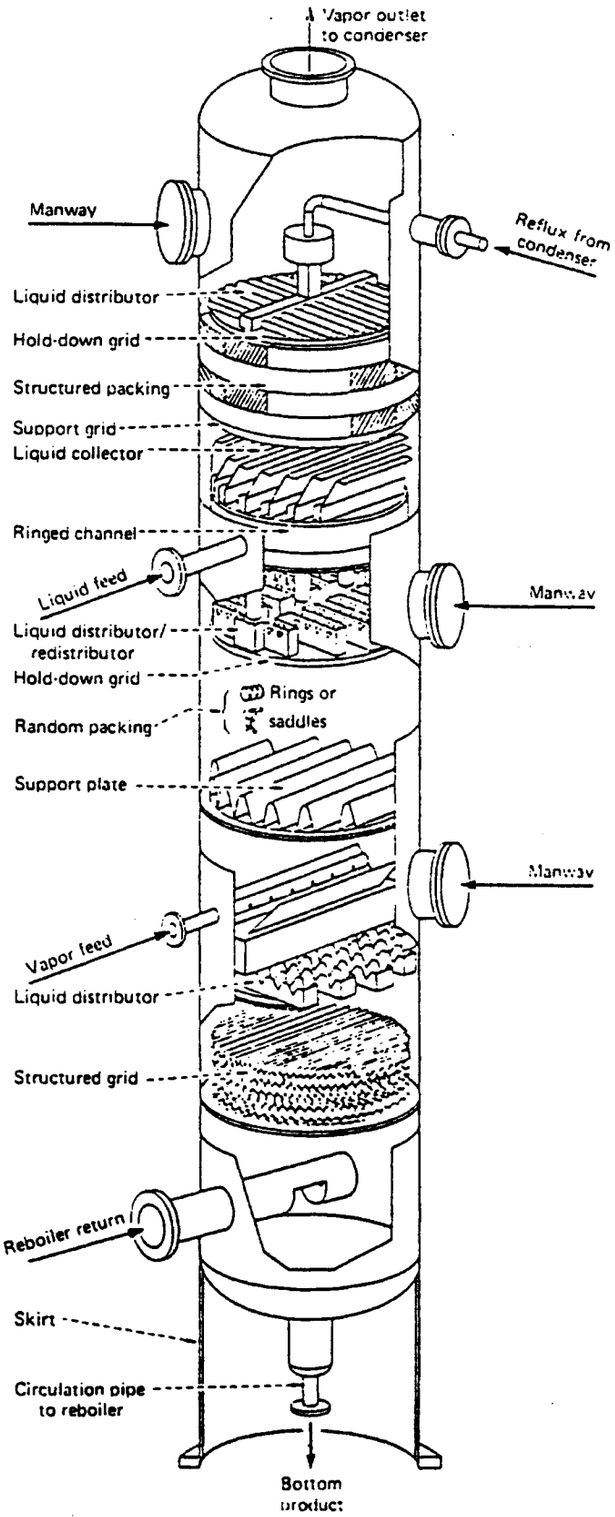


Fig. 1-1 Anatomy of a packed column showing various internals.(Chen, 1984)

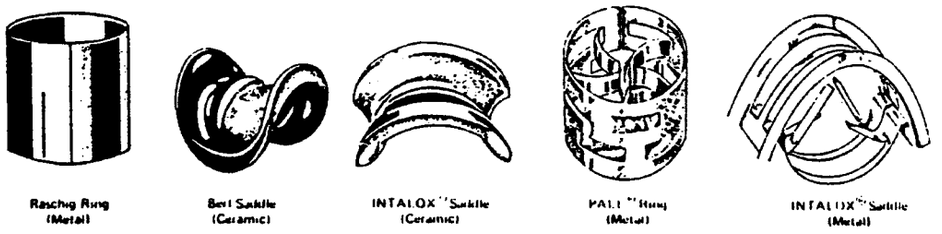


Fig. 1-2 Typical Random Packings.(Rousseau, 1987, p297)

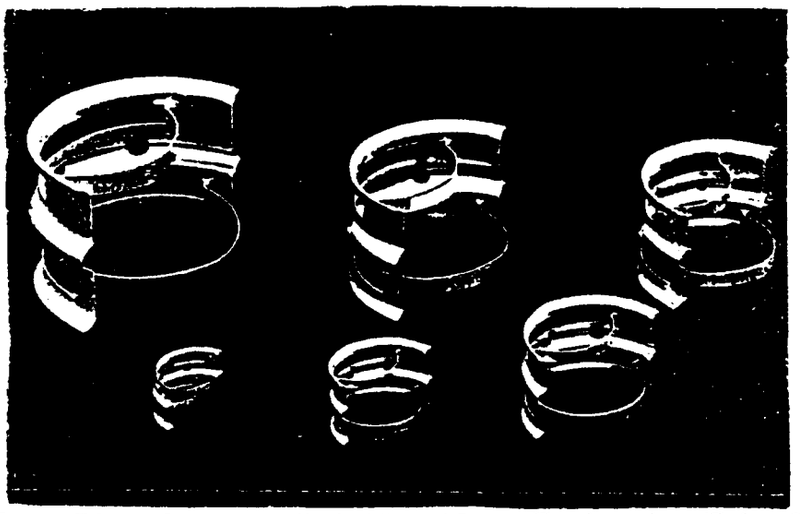


Fig. 1-3 Nutter Rings (Nutter Bulletin N-2 , Nutter Engineering, Tulsa OK, 1987)

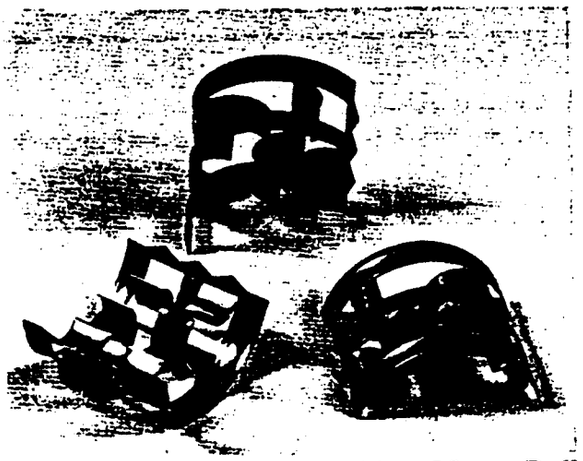
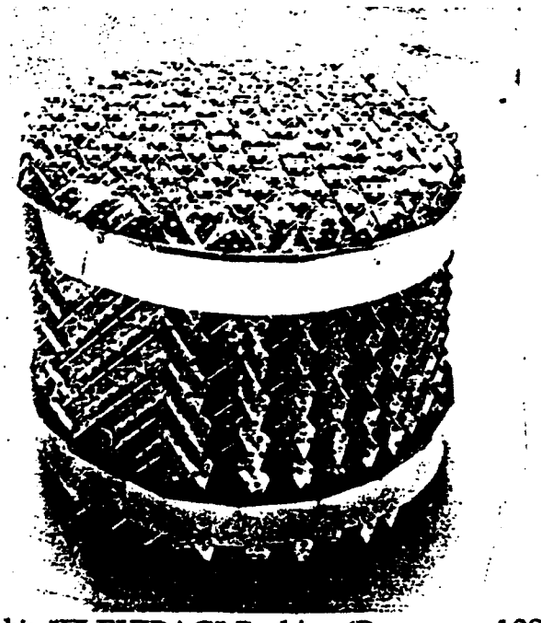


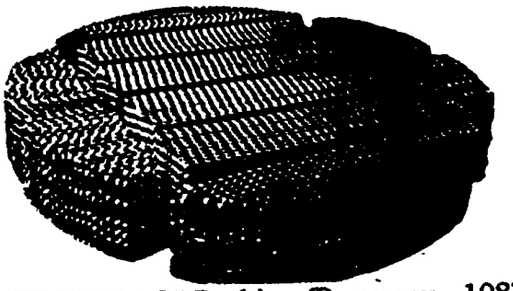
Fig 1-4 Nutter's "CHEMPAK" Random Packing (Nutter Bulletin N-2, , Nutter Engineering, Tulsa OK, 1987)

prospect of improved efficiency and purity offered by state-of-the-art packing can be seriously offset by a poor distribution system.(Chen, 1984) Early packings were typically of the Raschig ring type.(Fig 1-2) They had low efficiency and capacity and the distributors used were very simple in design. The introduction of Pall rings and variations thereof(Fig.1-2) made lower pressure drops possible. It was at this time that the importance of liquid distribution was recognized, since these packings were sensitive to initial liquid maldistribution. Today's high performance random packings permit fluids to flow through them and hence form drag is considerably reduced.(Figs1-3, 1-4 Nutter Ring, Norton's IMTP etc.) Structured packings(Fig1-5) also offer low pressure drop, very high surface area and high efficiency. The packing elements used in structured packing are generally made from sheets of corrugated metal sheet or gauze and the sheets are perforated. In addition the sheets are surface-treated so as to help spread the liquid film and thus to behave like the gauze surface which promotes liquid distribution by a capillary action.(Fair, in Rousseau, 1987) All these packings however, are sensitive to liquid and vapor maldistribution. Thus, for maximum efficiency, it is essential to have distributors which offer uniform distribution.

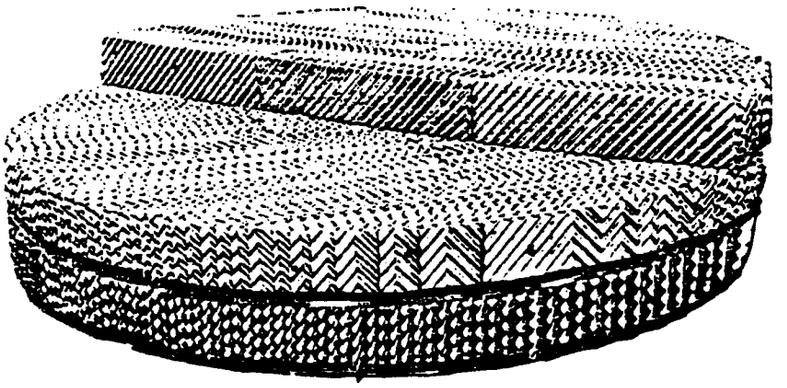
One of the ways to evaluate the performance of packings and the distribution systems associated with them is to plot log[X/(1-X)] vs. bed height, where X is the molar concentration of the light key in the liquid(Fig. 1-6). This method has been used by Fractionation Research Inc.(FRI.) in their studies on liquid distribution systems.(Zuiderweg 1987) The slope of the line thus obtained is directly proportional to the efficiency of the packing and is related to the performance of the bed and the distributor. If constant relative volatility is assumed, then a straight line(Curve **c**, Fig. 1-6) would mean a constant slope which in turn would imply constant efficiency. This would mean that the initial liquid distribution is sufficient for the desired separation. If the line is initially curved and then straightens out (Curve **b**, Fig.1-6), it means that the slope is increasing down the length of the bed. The initial curved portion represents poor initial



a) Koch's "FLEXIPAC" Packing (Rousseau, 1987, p297)



b) Koch's "FLEXIPAC" Packing (Rousseau, 1987, p297)



c) Nutter's "MONTZ" Packing (Nutter Bulletin N-2, Nutter Engineering, Tulsa OK, 1987)

Fig 1-5 Structured Packing

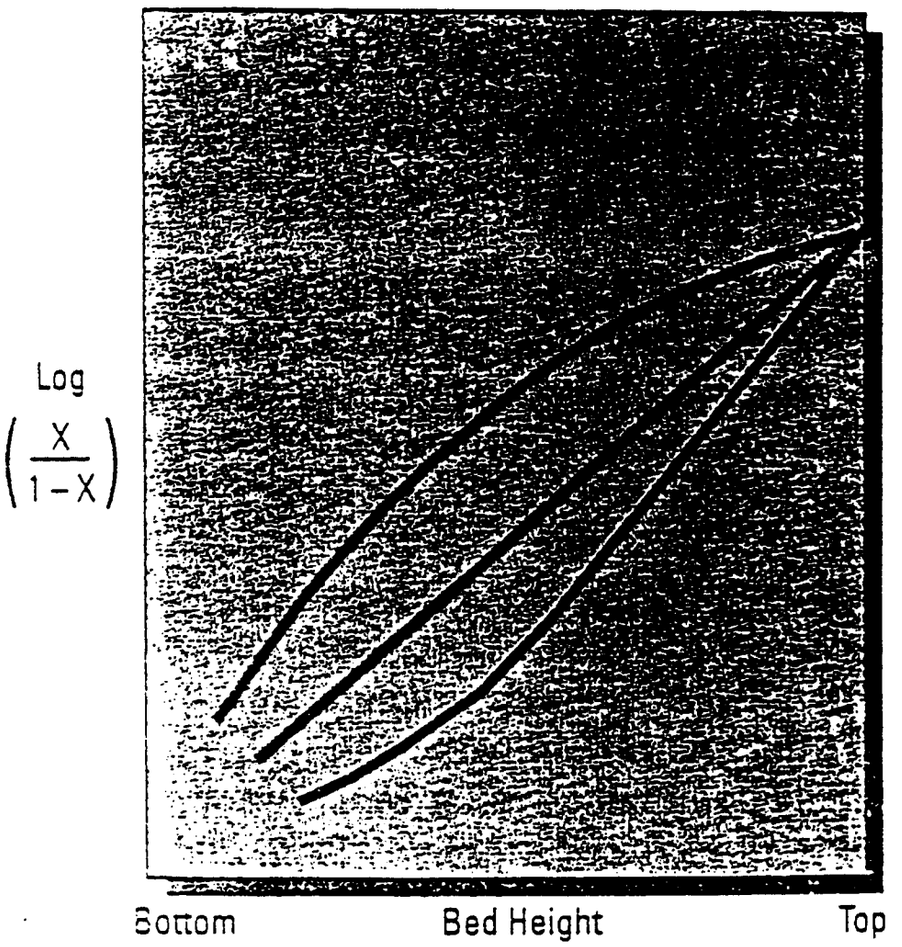


Fig. 1-6 Graph indicating performance of distribution system. (Bonilla 1993)

liquid distribution. The increase in slope down the bed would suggest that the packing efficiency is improving as the packing succeeds in spreading the liquid. Curve a in Fig.1-6 illustrates the case where a good initial liquid distribution deteriorates because of vapor maldistribution or excessively deep beds.(Bonilla 1993)

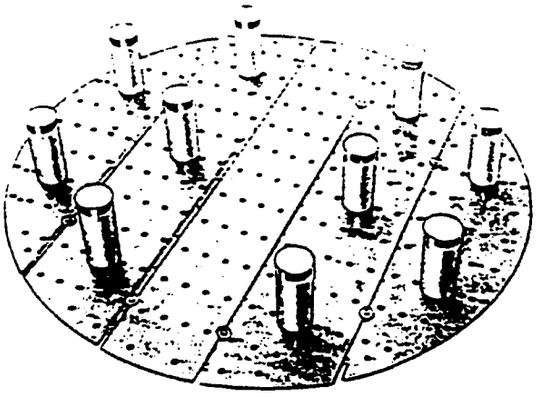
Types of Distributors

Distributors are broadly classified as a) Gravity b) Pressure and c) Flashing types, depending on the way the liquid is introduced.

a) Gravity Fed Distributors:

1) Pan Distributors: (Fig 1-7) These are also called Riser Tube Distributors(RTD). An RTD consists of a flat plate with orifices punched in it for distribution of the liquid. Vapor distribution risers are placed within the hole pattern in such a way that the hole layout isn't disturbed. Riser covers or caps are provided to prevent excess liquid from falling through. This type of distributor is generally used for small diameter columns in clean systems. When dealing with high vapor flows, narrow rectangular risers are preferred to circular ones because these provide a larger proportion of free area for vapor flow and also a larger number of drip points. Baffles may be used under the tray to distribute the liquid evenly to the packing immediately below the distributor.

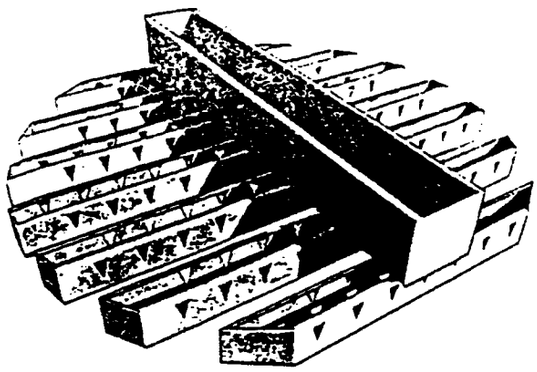
2) Trough Distributors:(Fig 1-8) This type of distributor consists of a series of troughs with circular orifices or V-notches punched in the bottom and/or sides. The troughs receive the liquid predistributed through parting boxes, which are mounted over the troughs, perpendicular to the orientation of the latter. These distributors are suitable for large columns, can handle large vapor flow rates and are easily leveled. Fairly large values of turndown(upto 5:1) can also be handled. However, large turndowns should not be specified unless absolutely required, because then it would be necessary to have multiple



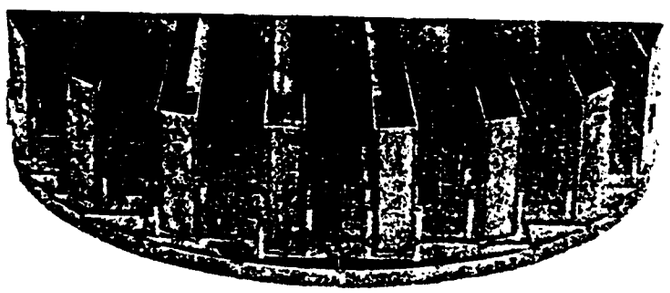
a) RTD With Circular Risers. (Chen, 1984)

b) RTD With Rectangular Risers.
(Bulletin TI-1, Nutter Engineering., Tulsa, OK, 1987)

Fig 1-7 Pan Distributors



a) V-Notch Distributor. (Chen, 1984)



b) Narrow Trough Distributor (Nutter Bulletin TI-1, Nutter Engineering., Tulsa, OK,1987)

Fig 1-8 Trough Distributors

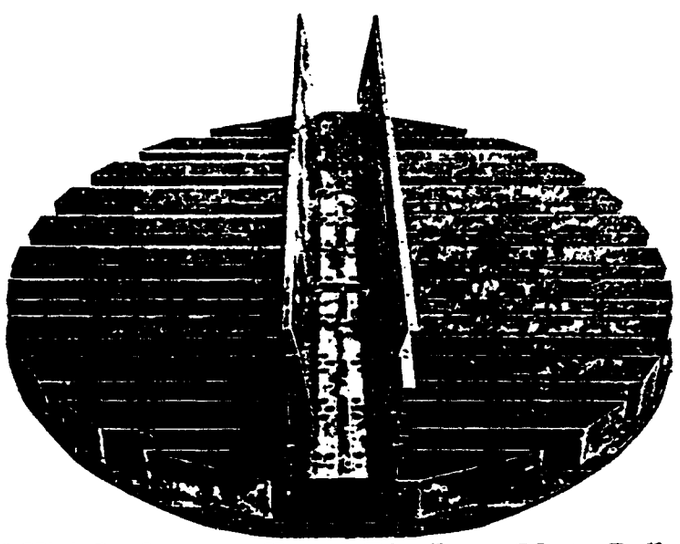


Fig. 1-9 High Performance Trough Distributor.(Nutter Bulletin TI-1, Nutter Engineering., Tulsa, OK, 1987)

levels of orifices, which do not provide as good a distribution as a single level. Also, large parting boxes would be required, which are expensive. Slurries and fouling problems can be handled if holes are punched in the sides of the trough instead of the bottom. This allows the solids to settle and avoids plugging of the holes. V-notch distributors are especially good for such cases. However, V-notch troughs are very sensitive to liquid maldistribution caused by out-of-levelness. Hence, these distributors should be avoided when dealing with packings with low HETP values and high purity products. Currently, high performance trough distributors are available(e.g. Nutter Trough Distributor) which feature a more uniform distribution pattern than the V-notch distributor, in addition to allowing flow equalization between troughs and better leveling capabilities. Such a distributor is shown in Fig 1-9.

3) Orifice Pipe Distributors:(Fig 1-10) This type consists of a pipe ladder arrangement with orifices drilled in the pipe. They are good for low liquid rate systems in small and medium size columns. This design provides a large free area for vapor flow. Hence, the pressure drop loss across the distributor is negligible. Since these distributors can be easily clogged, they should only be specified for clean systems.

b) Pressure Fed Distributors:(Fig 1-11): These are generally spray nozzle type distributors. The design of such a distributor is similar to that of a pipe orifice header except that spray nozzles are used instead of orifices. The number of nozzles per unit length is less than that of an orifice pipe. Distribution of the liquid is effected by overlapping circular cones of liquid spray issuing from adjacent nozzles. The overlapping prevents the occurrence of dry spots on the packing. These distributors are generally used for heat transfer and vapor washing, where no significant degree of fractionation is involved. Suitable mist eliminators should be used, especially when the mist generated by the spray could contaminate the overhead product.

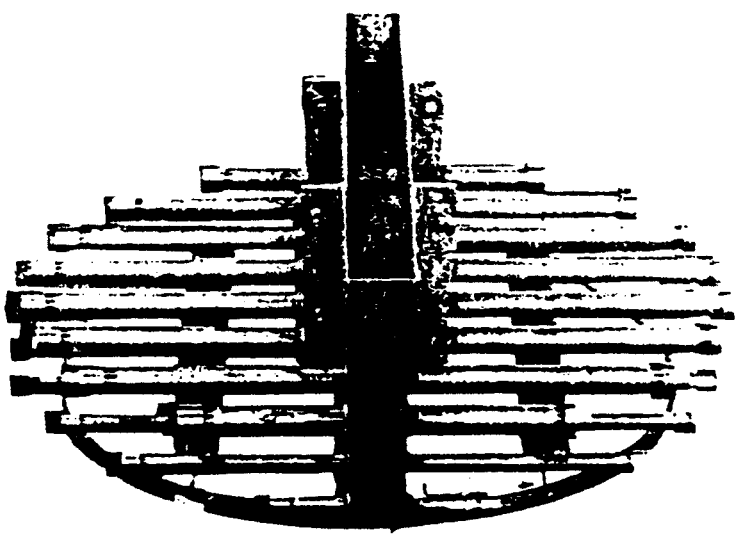


Fig.1-10 Orifice Pipe Distributor.(Nutter Bulletin TI-1, Nutter Engineering., Tulsa, OK, 1987)

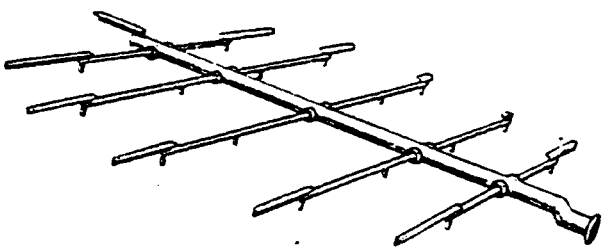


Fig.1-11 Spray Nozzle Header.(Chen, 1984)

c) Flashing Feed Distributors: These distributors have to first absorb the kinetic energy of the feed, then completely disengage the liquid and vapor and finally distribute the liquid to the bed below. There are two methods which are normally used to disengage the two phases and hence there are two types of flashing feed distributors.

1) Baffle Type:(Fig 1-12) This consists of a pan type distributor on which an impingement baffle is mounted. The feed is directed via slotted piping against the baffle and the two phases are separated. Baffle type distributors are suitable for small columns and are recommended for two phase feeds which do not produce a stable foam.

2) Gallery Type:(Fig 1-13) This distributor has a perimeter gallery mounted on the surface of the pan. The feed is discharged into this gallery where complete disengagement of the two phases occurs before the liquid falls into the distributor below. This type of distributor is capable of handling feeds which produce a stable foam. Generally, they are conservatively designed for large froth heights.

Selection of Distributors

The choice of distributor depends on several factors. The main criteria for selection are:

1) Degree of Fractionation Required

2) Liquid Flow Rate

3) Nature of Feed

4) Fouling Tendency

5) Turndown Requirements

6) Column Size

7) Type of Packing and Size

8) Number of Theoretical Stages

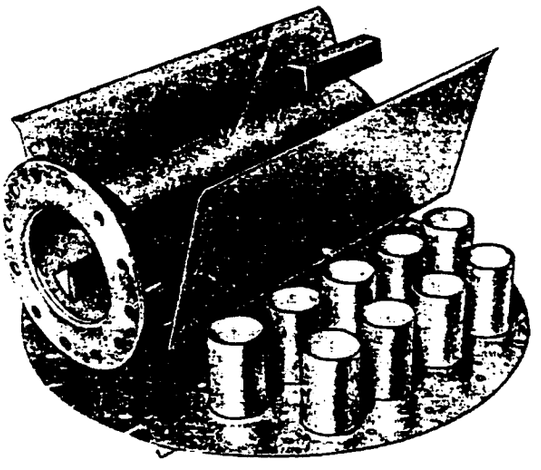


Fig. 1-12 Baffle Type Flashing Feed Distributor.(Chen, 1984)

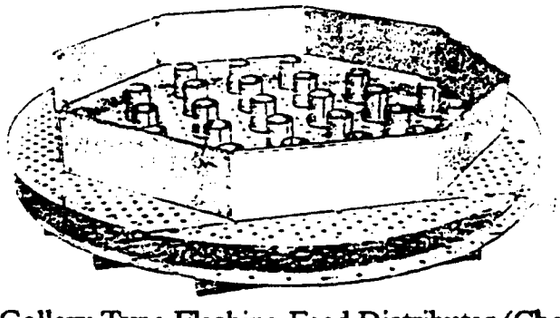


Fig 1-13 Gallery Type Flashing Feed Distributor.(Chen, 1984)

Table 1-1. Guidelines for Selection of Liquid Distributor(Bonilla, 1993)

	Type Of Distributor					
Factor	PAN (RTD)	POH (Gravity)	POH Pressure)	NTD	SNH	VND
Uniformity	VG	VG	F	VG	P	P
Solids Handling	P	P	F	G	G	VG
Turndown	G	G	G	G	P	P
Ease of Installation	F	F	G	F	VG	G
Ease of Leveling	F	G	VG	F	VG	F
As Redistributor	G (1,2)	No(2)	No	No (2)	No	No (2)
Height Requirement	M	L	VL	H	M	H
Cost	H	M	L	H	L	M
Residence Time	H	L	L	M	L	M
Suitable for Large Diameters (> 10 ft)	P	G	G	G	VG	G
Leakage Potential	H(3)	No	No	No	No	No
At High Vapor Rates	P	G	G	G	VG	G
At High Liquid Rates	G	G	G	G	VG	G
At Low Liquid Rates	G	VG	G	VG	P	P
For High Degree of Fractionation	VG	VG	P	VG	P	P
Heat Transfer	G	G	F	G	VG	G
Liquid Feed Handling	Yes (1)	No	No	Yes	No	Yes
Flashing Feed Handling	Yes (1,2)	No(2)	No	No (2)	No	No(2)

Key:
RTD-Riser Tube Distributor; POH-Pipe Orifice Header; NTD-Narrow Trough Distributor; SNH-Spray Nozzle Header; VND-V-Notch Distributor

VG = Very Good; G = Good; F = Fair; P = Poor
H = High; M = Moderate; L = Low; VL = Very Low
"No" means that the distributor cannot be used for the particular application

1 No significant liquid mixing provided, however.
2 Very good if used in conjunction with a chimney tray
3 Leakfree if seal welded

Bonilla(1993) gives some guidelines for selection of liquid distributors. These are reproduced below in Table 1-1

Liquid Maldistribution:

There are two types of liquid maldistribution which can occur in a packed column. The first is the small scale maldistribution which is characteristic of the packing type used.(Zuiderweg 1987) This phenomenon has been shown to have only a minor effect on the efficiency of the column.(Zuiderweg 1987) The second type of maldistribution is the large scale maldistribution which is a direct consequence of imperfect initial liquid distribution. This can significantly affect the operation of the column. Some of the reasons for poor initial distribution are over-irrigation, under-irrigation, interference by support rings, inadequate number of drip points near the wall, flashing feeds, high velocity flow in parting boxes and troughs, out-of-levelness, foaming and finally fouling. Much work has been done in the last five years on liquid maldistribution. Some of the details will be presented in the next chapter.

Distributor Design:

For a trough type distributor, the design parameters fixed by the system are the liquid and vapor flow rates per unit area of tower cross-section, the pressure drop, turndown ratio and the physical properties of the fluids. The dependent parameters are the drip point density(number of orifices per unit area), hole diameter, hole layout, number and width of troughs and the liquid head in the distributor. Once a particular type of distributor has been selected, and the geometrical parameters specified, all that needs to be known is the liquid head in the trough. Using Bernoulli's Equation to describe the various head terms, the following simple equation is obtained to relate velocity through each

orifice(V_O) and corresponding liquid height(h) over the orifice:(Derasari 1992 and Chap 2, this work)

$$V_O = C_O(2gh)^{1/2} \quad \text{..... (1-1)}$$

C_O is called the orifice coefficient. This term accounts for jet contraction, kinetic energy correction and friction effects. The value of the orifice coefficient is always determined experimentally. Another coefficient which is often used to describe the flow of a liquid through orifices is the contraction coefficient(C_C). It is defined as the ratio of the area of the jet at the minimum cross-section to the orifice cross-sectional area.(Eqn 1-2).

$$C_C = (A_j)_{min}/A_O \quad \text{.....(1-2)}$$

This study is concerned with the determination of the orifice coefficient and the corresponding relation between the orifice flow rate and the head in the distributor.

Overall Project Description:

(Bell, Johannes and Kunesh 1991)

The main objectives of the research program are:

1) To determine experimentally the values of orifice coefficients for holes used in distributors. This would also include analysis of the effects of manufacturing tolerances and methods, hysteresis, direction of punching relative to the flow , hole sizes and plate thicknesses.

2) To determine experimentally the effects of interaction among adjacent holes upon the orifice coefficient.

3) To determine experimentally the effect of liquid crossflow(in the horizontal direction)on the orifice coefficient.

4) To develop a numerical computer-based hydrodynamic model for flow in the distributor for design and operation of various liquid distribution systems for packed columns. The

experimental data from 1), 2) and 3) will be used to provide values of the orifice coefficient and to check the predictions made by the model.

Scope of This Work:

Most of the data collected thus far have been single orifice data and hence were related to Objective 1) of the project. Derasari(1992) has described the effects of various parameters upon the orifice coefficient, based on the data he collected. The present study consisted of two phases. Phase 1 involved collecting more orifice coefficient data on single orifice plates. Phase 2 included tests on an actual distributor trough. The effect of interaction among adjacent holes was studied and distribution patterns observed. Comparisons were made between the data obtained on the trough and the predictions made using Derasari's data and that obtained from Phase 1. The trough tests used three different inlet pipe positions, one of which involved the use of a flow calming device to break up the momentum of the inlet stream to the trough. These data are to be used to develop the hydrodynamic distributor design model.

CHAPTER II

LITERATURE REVIEW

The flow of fluids through orifices has been studied by a large number of researchers. Most of the data obtained has been for orifice flow meter applications, i.e. for pipeline flow. Very little data is available from actual distributor studies. Most of the work on distributors has been carried out by FRI(Kunesh et al..(1985, 1987)) and by the Delft Technical University, Holland (Zuiderweg et al..(1978, 1987)). Open channel flow and flow through orifices discharging from distribution channels have been extensively reported in the literature, but these papers are mostly in the field of civil and environmental engineering. However, the basic fluid mechanics principles involved therein can be used to describe the flow through distributors. The literature for this study is broadly divided into the following sections:

1) Flow Through Orifices

2) Distributor Studies

Flow Through Orifices

Derasari(1992) compiled a comprehensive literature review on flow through orifices. The bibliography he cites relates to orifice coefficient data, flow through an orifice from a transverse stream, contraction coefficients, nature of discharge jets and available correlations for determining the orifice coefficient and the relationship between the head and the flow rate.

Orifice Coefficients and Reynolds Numbers: Tuve and Sprenkle(1933) were among the first to present orifice flow data in the form of an orifice coefficient-Reynolds number plot. They mention that subject to an error of 1.5% attributable to geometrical uncertainties and surface finishing, the Reynolds number approach is useful for obtaining a generalized correlation. Pollard and Iwaniw(1984), in their study on the effect of corner rounding of sharp edged rectangular orifices found little difference between the resulting velocity profiles. Another study which related orifice coefficients and Reynolds numbers was carried out by Medaugh and Johnson(1940). They found the coefficient of discharge to be about 0.588. This value appears to be lower than that obtained by us in this work. Further work is underway at O.S.U. to determine whether the Reynolds number can indeed be used as a correlating parameter.

Discharge Jets: The hydrodynamics of a free liquid jet issuing from a sharp edged orifice was studied by Iciek(1981). He showed that, for turbulent flow, the jet from the orifice could occupy the full orifice crosssection without wetting or with partial wetting of the inner walls. The reason for the transition from full cross section flow to flow without wetting is the entrapment of air in the so-called "dead zone". Iciek(1982) also found that laminar jets are very unstable and the nozzle geometry has a negligible effect on the jet hydrodynamics. The reader is referred to Derasari's thesis for a discussion on jet structure and break up. In this discussion, Derasari describes various relationships and dimensionless numbers associated with the breakup length, as cited in the literature. Obot, Graska and Trobold(1984) studied round jets at moderate Reynolds numbers($13000<Re<20000$), and discovered that as the l/d ratio decreases, the jet decays and spreads more rapidly and also entrains more fluid.

Effect of Various Parameters on Flow and Orifice Coefficient: Judd and King(1906) presented results of their experiments relating to flow meters. They concluded that the discharge and contraction coefficients(Eqns 1-1 and 1-2) both decrease as the size of the orifice increases. They also found that an increase in static pressure does

not influence jet contraction when there is no velocity of approach. Also, the average value of the orifice coefficient was found to be 0.6066. Derasari(1992)drew the following conclusions from his experiments on square-edge orifices:

1) For Re<4500, the orifice coefficient decreases with a decrease in the l/D ratio. The effect of plate thickness is comparatively less than the effect of hole diameter. Also, in laminar flow,(Re<2100) the value of the orifice coefficient increases as the Reynolds number increases and reaches a maximum value after which an increase in Reynolds number will cause the orifice coefficient to decrease.

2) Some hysteresis and deburring effects were observed. These effects were not reproducible which suggests that they are unpredictable. However, hysteresis is more liable to occur in the low Reynolds number region.(Re<10000)

3) The orifice coefficients obtained using punched holes were slightly greater than those using drilled holes. This effect becomes less significant as the plate thickness decreases but more evident at lower heads.

Most of the results obtained in the present study were consistent with those cited above. Very few readings were taken in the low Reynolds number region. This was because it was felt that to simulate actual operating conditions, it was necessary to maintain a minimum head of 2 inches in the distributor. This corresponded to a Reynolds number of 6000 to 7000, which was probably why no significant hysteresis effects were observed.

An interesting observation was recorded by Lockett and Banik(1984) in their study on weeping from sieve trays, which can be compared to the flow of liquid through the orifices in a distributor. They used three different hole sizes for the sieve trays viz. 3 mm, 6 mm, and 12.7 mm. diameters. It was observed that the weeping rate was a maximum for the 6 mm diameter holes with the 3 mm and 12.7 mm holes both exhibiting lower weeping rates. Fig. 2-1 shows their results. They also observed that weeping occurred by different mechanisms for the three holes. For the 3 mm holes, severe bridging of the liquid

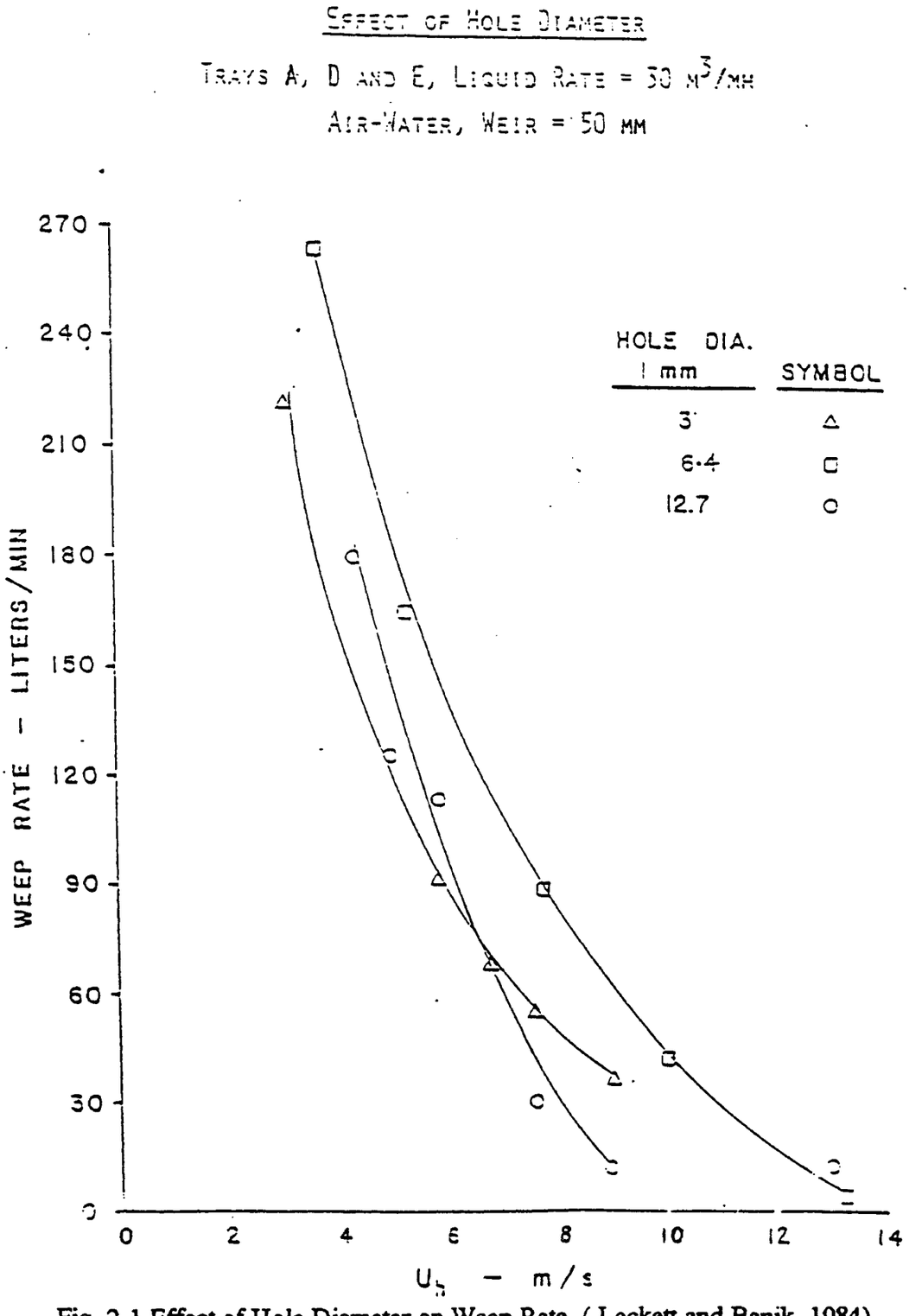


Fig. 2-1 Effect of Hole Diameter on Weep Rate. (Lockett and Banik, 1984)

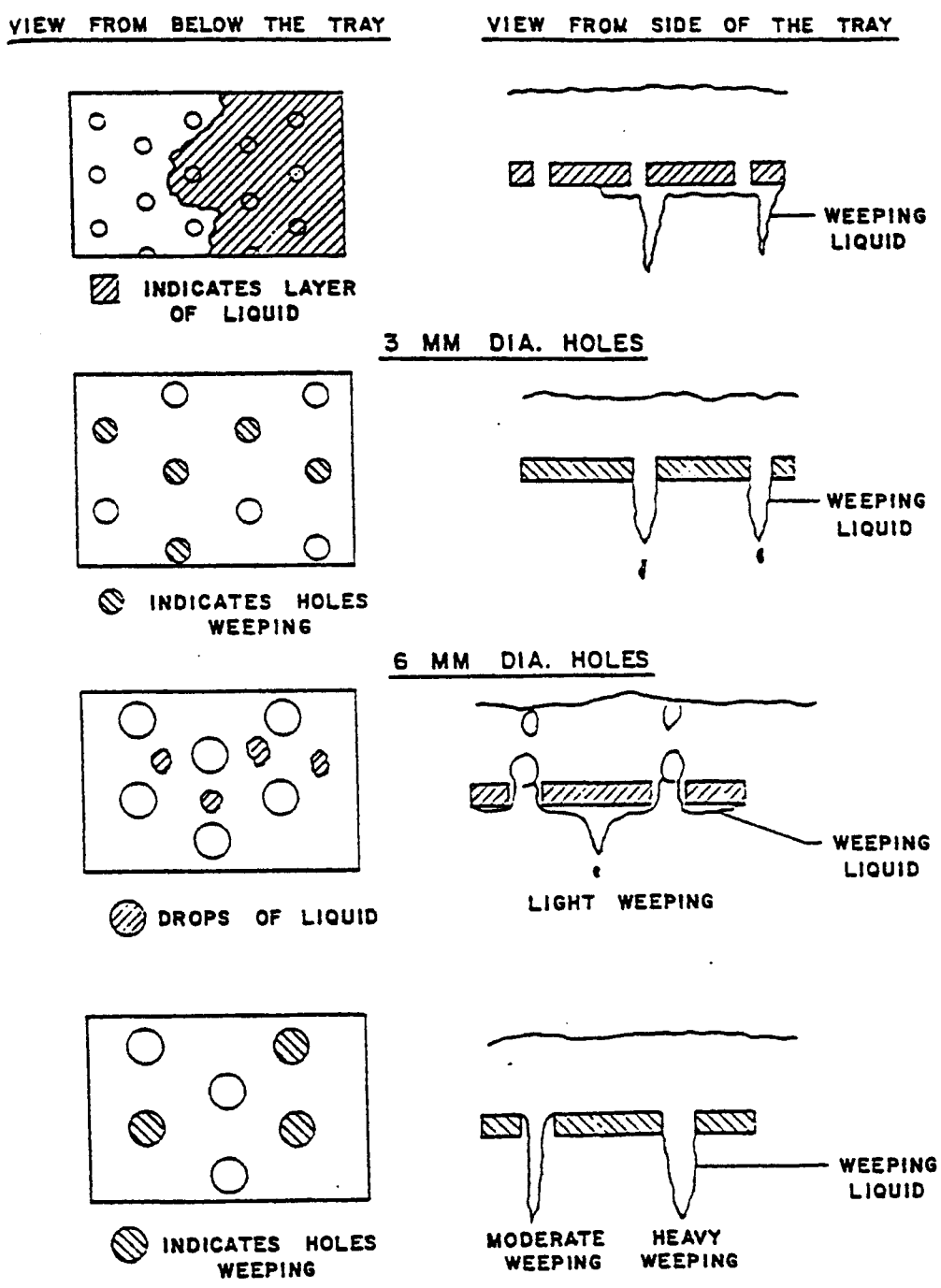


Fig. 2-2 Mechanisms of Weeping. (Lockett and Banik, 1984)

occurred under the tray. Liquid discharged as streams from a layer which covered the underside of the tray. For the 6 mm holes, liquid discharged as jets, independent of the weep rate. For the 12.7 mm holes, the mechanism varied depending on the weep rate. Fig. 2-2 shows the different weeping mechanisms.

Flow in Conduits and Open Channels: In their experiments on the flow through an orifice from a transverse stream, Andrews and Sabersky(1990) were particularly interested in flow situations for which the dynamic pressure of the flow along the wall was important in relation to the dynamic pressure in the orifice. They found that the discharge coefficients thus obtained differed from those quoted for discharge from a large reservoir. Typically, an increase of 30 to 40 % in the magnitude of C_0 was observed. This was attributed to unsymmetrical flow, the influence of the velocity profile, and the dynamic pressure of the main stream along the wall. Fig. 2-3 shows their results. The flow in distribution channels with was analyzed by Hager(1986) using a hydraulic approach. The effects of frictional slope, additional head loss due to the lateral openings and lateral outflow are considered. It was concluded that the discharge coefficient depended only on the shape of the lateral opening and was independent of dynamic effects.

Benefield et al.(1984) describe a stepwise computational procedure for determining the flow distribution in a rectangular channel in which rectangular sharp edged submerged orifices are used for flow control. This algorithm was first presented by Chao and Trussel(1980). The flow characteristics of each orifice are determined by going stepwise from the downstream end of the distribution channel to the upstream end. A similar analysis is applicable when rectangular side weirs are used for flow control. Ramamurthy and Carballada(1979) used free streamline theory and the Schwarz-Christoffel transformation to obtain a solution to the problem of flow past a lateral outlet. They were especially interested in studying outlets set at arbitrary inclinations. The jet contraction coefficient and jet inclination were expressed in terms of the jet velocity

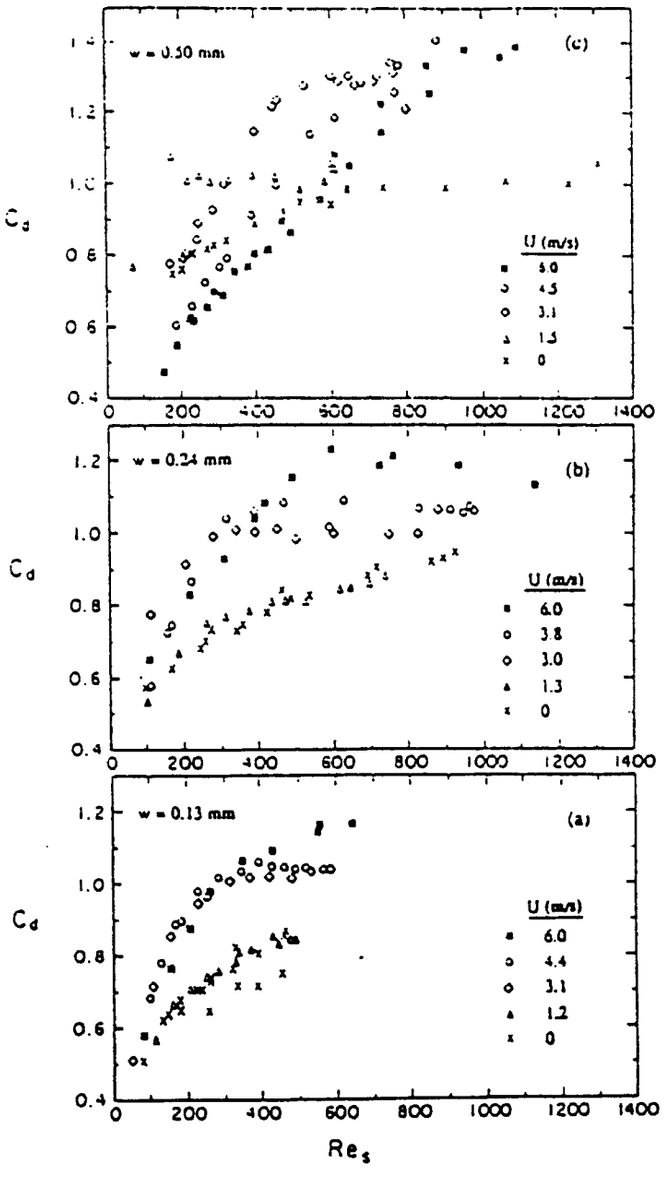


Fig. 2-3 Discharge coefficient Cd vs Reynolds number Res for different pipe velocities and slot widths. (Andrews and Sabersky, 1990)

ratio. Fig. 2-4 shows a schematic representation of the physical model. It was found that the contraction coefficient C_c decreased for increasing values of the jet velocity ratio η. Also when $\eta \rightarrow 0$, the contraction coefficient increases from 0 to 0.61 as the barrier inclination varies from π to $\pi/2$. These results may be useful in further studies on distributors where the effect of the horizontal velocity component has to be considered. Ramamurthy et al..(1986) also studied the flow through rectangular lateral orifices in open channels and obtained an expression for the mean orifice discharge coefficient in terms of two parameters. The first parameter relates the length of the orifice and the width of the main channel. The second denotes the ratio of the mean velocity in the main channel to the resultant velocity of the jet through the orifice. When a reduction factor of 0.95 was applied to account for the velocity distribution of the flow in the main channel, it was observed that their experimental data and the values of the orifice coefficient calculated using the proposed equation were in good agreement. In another article, Ramamurthy et al.. (1987) studied lateral orifice-weir units.(Fig. 2-5) They proposed an expression to relate Q_r to various geometrical parameters and the Froude number of the approach flow, where Q_r is the ratio of the flow rate through each lateral orifice-weir unit to the total inlet flow rate.

Distributor Studies

Small Scale Maldistribution (Maldistribution and Packings): Hoek(1983) studied liquid flow in a packed column on a scale comparable with the packing size. He found that every packing has a characteristic "natural liquid flow distribution". This distribution will be reached irrespective of how good or bad the initial liquid distribution is. However, for any distributor, there exists an initial distribution which will minimize the packing height required to achieve this "natural distribution". Zuiderweg and Hoek (1987) found that the natural flow maldistribution apparently does not have a significant effect on the

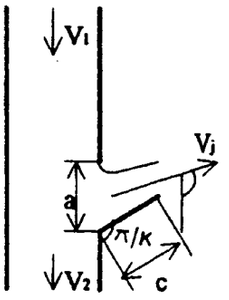


Fig. 2-4 Physical Model For Flow Past a Lateral Outlet
(Ramamurthy and Carballada, 1979)

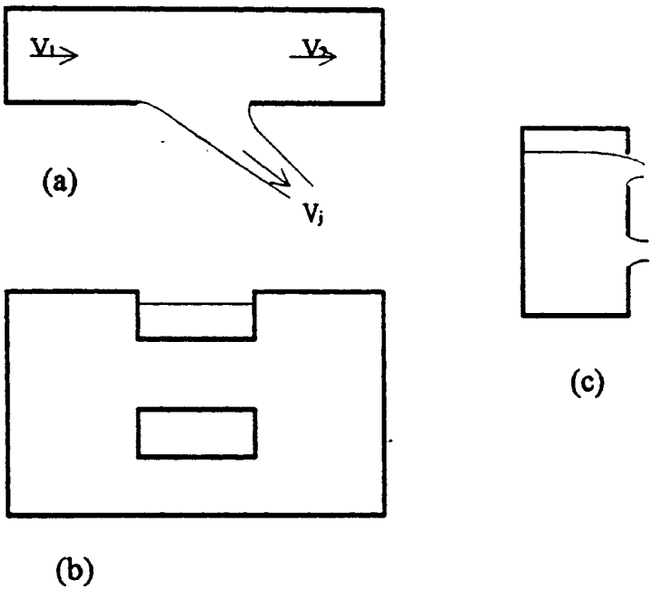


Fig. 2-5 Weir-Orifice Unit: (a) Plan View; (b) Front View; and (c) Sectional View
(Ramamurthy et al., 1987)

separation efficiency of the packing. They also concluded that separation efficiency is best expressed in terms of HETP(Height Equivalent to a Theoretical Plate) because it almost independent of the liquid/vapor flow ratio. Albright (1984) used a computer model to simulate flow of a liquid through a packed bed. Different distributor designs were tested using this model. He confirmed the existence of a natural flow distribution. Perry et al.. (1990) define a "recovery length" as the bed height required for the packing to achieve its natural liquid distribution. They use Hoek's concept of a radial spreading coefficient(1986) to describe the recovery length. The radial spreading coefficient is a measure of how quickly a packing can spread a vertical stream radially as the liquid progresses down the column. The greater the value of the coefficient, the shorter is the recovery length. Larger packings have larger values with some exceptions depending on the shape of the packing. In general, structured packings have higher coefficient values than random packings. However, since spreading is not random, multiple layers are required to redistribute the liquid in all directions. Fig 2-6 shows some typical values of radial spreading coefficients for a few packings. Earlier, Bemer and Zuiderweg (1978) in their study on liquid spreading and distribution patterns had analyzed the effect of various parameters on liquid spreading. Some of these included wettability of the packing, packing size, bed height and flow rate. They found that radial spreading depended mainly on the packing size. They also observed that the local flow rate in the column was significantly different from that predicted by diffusion theory. Hence they defined a maldistribution factor and again found that it depended chiefly on the packing size.

Large Scale Maldistribution: In the simulation studies referred to earlier, Albright (1984) also drew the following additional conclusions:

a) It is important to have homogeneous flow, i.e. equal flow throughout, from any distributor. This is especially critical for systems with high column diameter/packing diameter ratios.

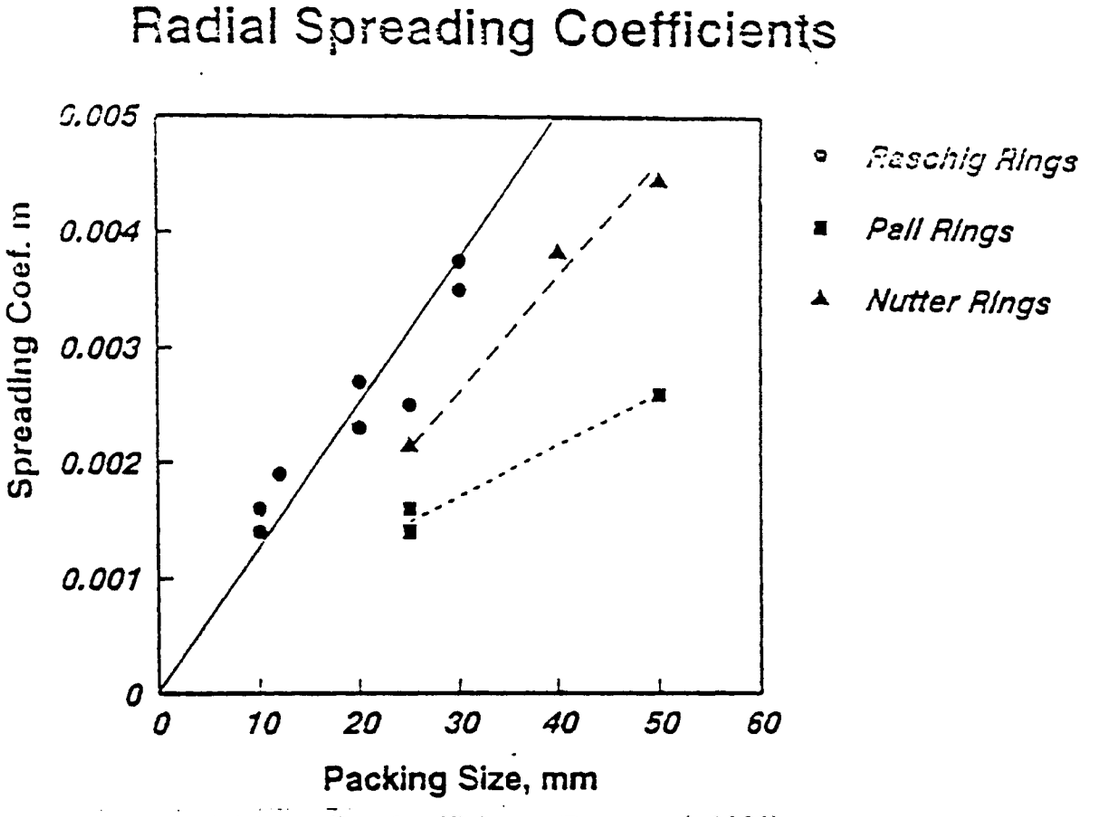


Fig. 2-6 Radial Spreading Coefficients. (Perry et al, 1990)

b) The wall effect, or channeling of liquid down the sides of the column, is more pronounced for smaller column diameter/packing diameter ratios.

c) Support rings can cause bed blanking(non-irrigation of some part of the bed) to occur and should not be used with drip type distributors. Also, for these type of distributors, levelness of the distributor is critical.

Zuiderweg and Hoek (1987) also analyzed the effect of initial liquid maldistribution on column efficiency. They studied this effect using a combination of two models, a radial liquid flow model and a zone-stage mass transfer model. They found that when the initial liquid distribution is reasonably good, redistribution is normally not required. This is usually the case for large packings(D_p > 50 mm). Smaller packings (D_p < 50 mm) are more sensitive to the quality of initial liquid distribution and redistribution may be required. If redistribution is provided then the best results are obtained if the liquid and vapor are both radially remixed in the redistributing device. They also found that the ill effects of initial maldistribution can be reduced when the liquid concentration driving force is smaller, i.e. for small values of relative volatility, for extreme concentrations, and for partial reflux. Recommendations are made for the for the number of pour points that should be provided per unit area in the distributor.

According to Perry et al. (1990), the quality of liquid distribution depends mainly on the following three factors:

i) Distribution Point or Pour Point Density: Most designs use 40 -100 points/m^2(4-10 points/ft^2). Generally, smaller packings require a higher density.

ii) Geometric Uniformity of Pour Points Across The Cross Section: The most common problem with distributors is the under-irrigation of the wall zone. To account for this under-irrigation, Nutter advocates maintaining a set of radially distributed pour points within one packing diameter of the wall. This analysis is subject to the mechanical limitations of the distributor system.

iii) Uniformity of liquid flow from the pour points: Some of the factors affecting the uniformity of liquid flow from the distributor are levelness, fit-up tolerance, punch reproducibility, and liquid velocity. The authors recommend the use of a distributor test stand for testing distributors before installation. This is especially useful for critical services and large diameter columns. The analysis of various distributor designs indicates that the deviations from uniform flow have normal distributions.

The coefficient of variation(C_V), which is the percentage ratio of the standard deviation to the sample mean, is a good means of describing maldistribution. The normal range of C_V for reasonable distribution is 3-30%. When using the test stand, the C_V value should be less than 5% so that an ultimate commercial C_V value of less than 10% can be obtained. Using statistical analysis for confidence interval estimates, it can be shown how many points must be sampled to assess distribution performance. This is especially useful for large distributors with thousands of pour points. For complicated designs, stratified sampling is recommended.

Kunesh et al..(1987) used an adjustable distributor to study liquid maldistribution in packed beds. This was part of a program in which controlled maldistribution was studied to provide guidelines for the design, fabrication and installation of commercial distributors. They considered two types of maldistribution patterns:

1) Uniform Maldistribution: These included
   a) Sag Towards the Center
   b) Sag Towards the Wall
   c) Tilt
2) Discontinuities in flow: These included:
   a) 11% Chordal Blanking
   b) 16% Center Blanking

It was seen that, from an overall efficiency view point, flow discontinuities had a more severe effect than sag/tilt effects. They also used Hoek's(1987) zone-stage model to

describe the column performance. First, they defined the geometric coverage of the distributor as the area enclosed by straight lines drawn through the outermost pour points. However, to use Hoek's model, they had to introduce the additional concept of "effective coverage". This was to account for the streams widening and splashing as they issue from the top of the bed. It involved the use of a fictitious extra bed length. The results obtained seemed to be consistent with Zuiderweg's (1987) plots of geometric and effective coverage. Use of the Zuiderweg/Hoek model in simulating their results apparently confirmed the existence of a basic HETP which is independent of the initial liquid distribution. It also confirmed that a relationship exists between the geometrical and effective coverage, independent of the packing.

An overview of liquid distributors is presented by Bonilla(1993), in which he gives practical guidelines for selection, design and installation of the right distributor. He describes types of distributors, selection criteria, steps for evaluating and designing distributors and techniques for testing and troubleshooting.

CHAPTER III

DESCRIPTION OF EXPERIMENTAL APPARATUS

All the experimental work in this study was done using the pilot plant scale recirculating loop which was designed and constructed by Derasari and Chatorikar. (Derasari, 1992) In his study on square edged orifices, Derasari took water directly from the building's main water supply line. In this work, the orifice plate data were collected using the constant head tank of the recirculating loop as a water inlet. A very brief description of the orifice plate test facility will be presented before the trough tests are described. For other details of the apparatus, the reader is referred to Derasari(1992).

A sketch of the apparatus is shown in Fig. 3-1. It basically consists of a cylindrical Plexiglas tank supported on a steel frame. The orifice plates were held between flanges and sealed with O rings to the base of the cylinder. Head readings were taken using a liquid level indicator made of glass. The level indicator was connected to a flexible tube which was inserted into a nipple which was fixed to the underside of the orifice plate. The nipple had a hole which was flush with the top surface of the orifice plate so that the zero point could be accurately read. The major difference between Derasari's experiments and the present work was that, in this study, the constant head tank in the recirculating loop was used to supply water to the cylindrical tank. This offered better control and also eliminated any line flow fluctuations. The water was not recirculated. Other differences in experimental technique included using the electronic turbine flowmeter to measure the flow rate. From time to time, the flow rate was also measured using a measuring cylinder and stopwatch using a collection of twenty to thirty seconds. For data reduction, a

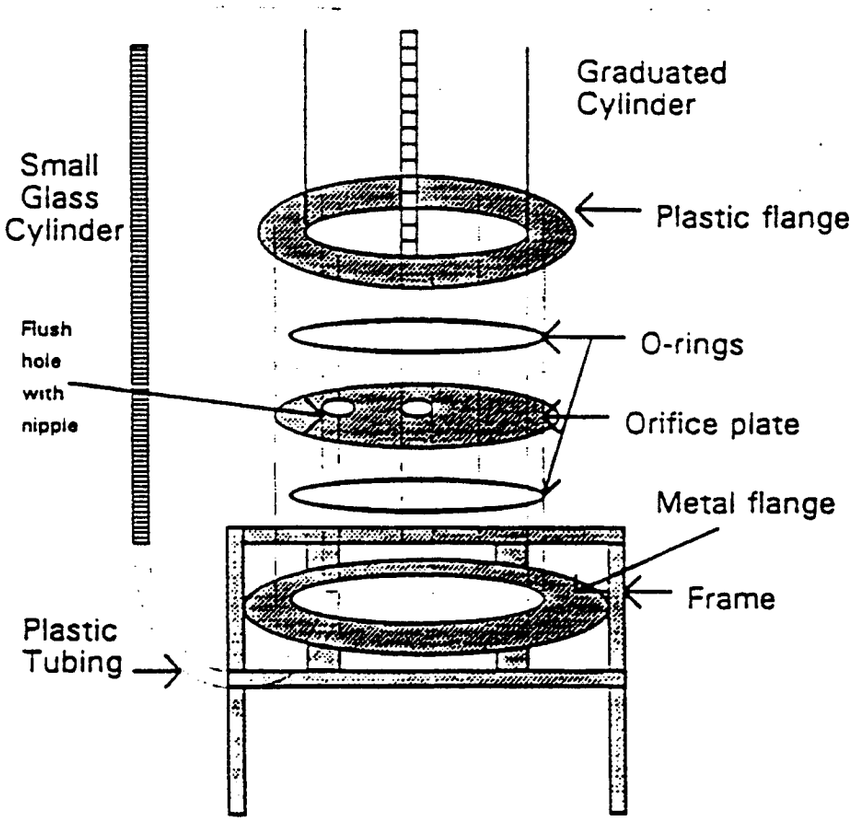


Fig. 3-1 A Schematic Diagram of the Single Orifice Test Facility. (Derasari, 1993)

correlation was used to accurately calculate the viscosity at the measured temperature. Plates supplied by four different manufacturers were tested. The nomenclature for plate identification is consistent with that used by Derasari, but needed to be extended to include plates supplied by additional manufacturers. Appendix 1 gives the nomenclature used. Hole diameter measurements are tabulated in Appendix 2.

Recirculating Loop

This experimental facility(Fig. 3-2) was designed primarily to test different liquid distributors. In this study it was used to obtain data on a trough type distributor. The basic components of the system are:

1) Feed Tank
2) Pumps
3) Constant Head Tank
4) Flow Meters
5) Collection Trough
6) Associated Piping, Supporting Structures, Electrical Connections

The feed tank was first filled with water, which was used as the test liquid. From the feed tank the water was pumped to the constant head tank, which was mounted 10 ft above floor level. Globe valves were used to give a controlled output flow from the constant head tank. Turbine flowmeters were used to measure this flow rate. The water was then discharged into the distributor trough. The collection trough, mounted below the distributor, collects the water and returns it to the feed tank.

Distributor Trough

(Figs. 3-3 & 3-4) A stainless steel trough type distributor supplied by Nutter Engineering was used to study the effect of the interaction of adjacent holes on the orifice

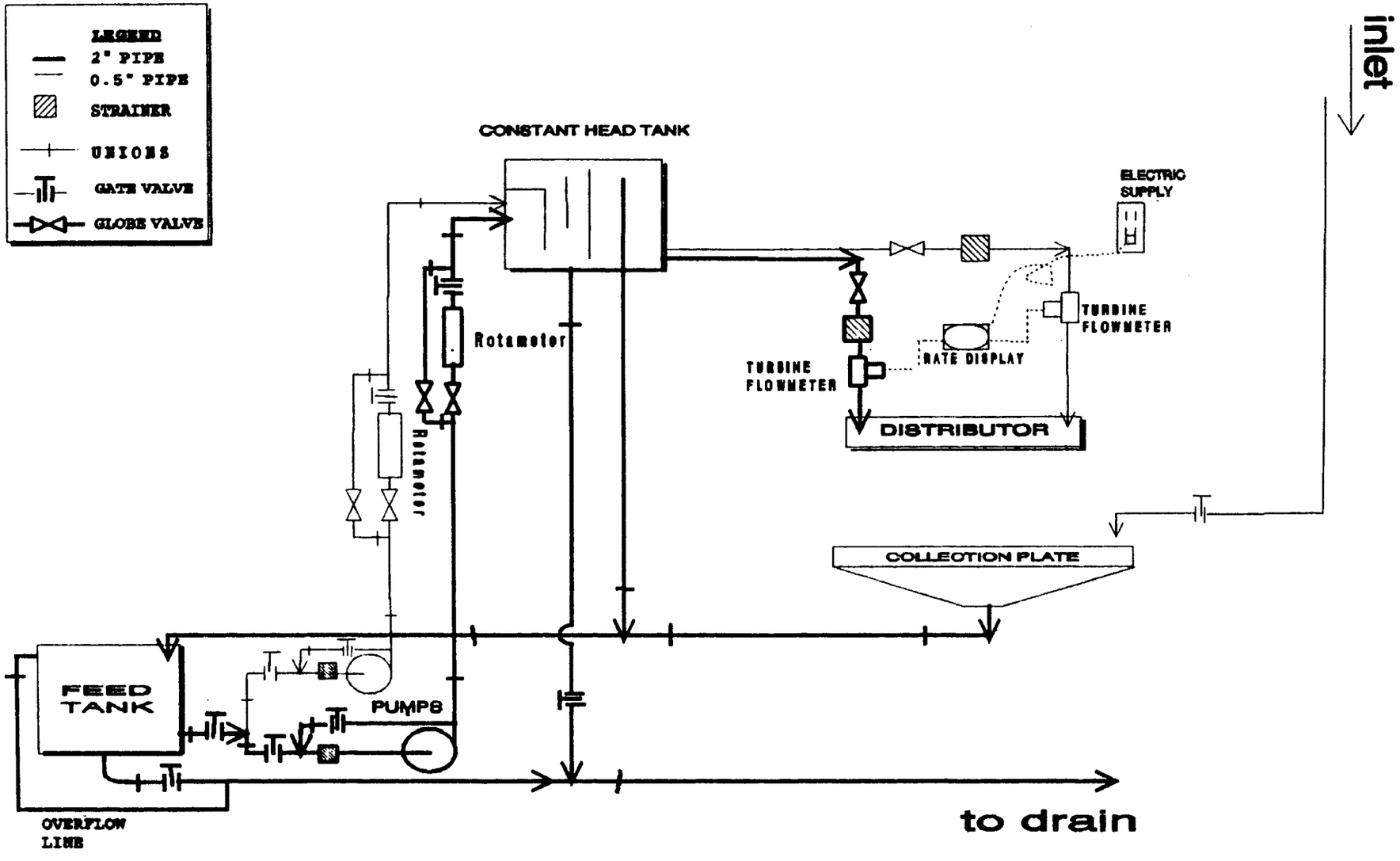


Figure 3-2. A Schematic Diagram of the Recirculating Loop(Derasari, 1992)

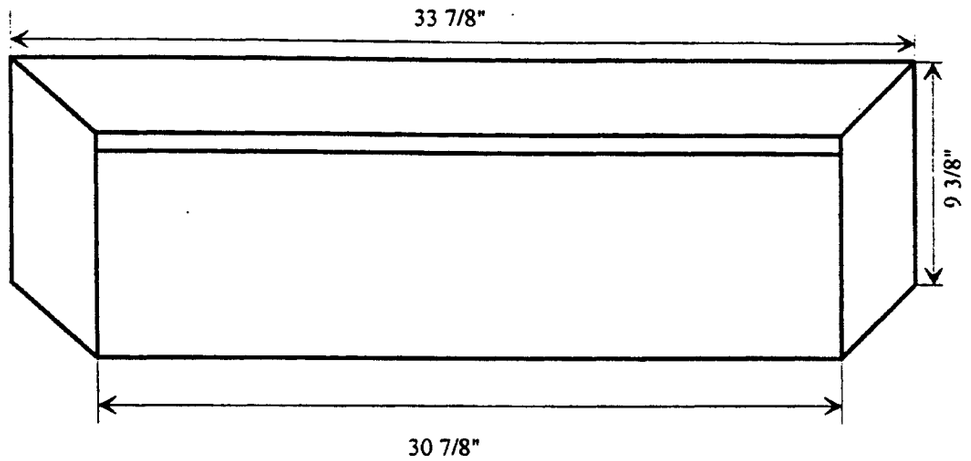


Fig 3-3 Schematic Diagram of Distributor Trough

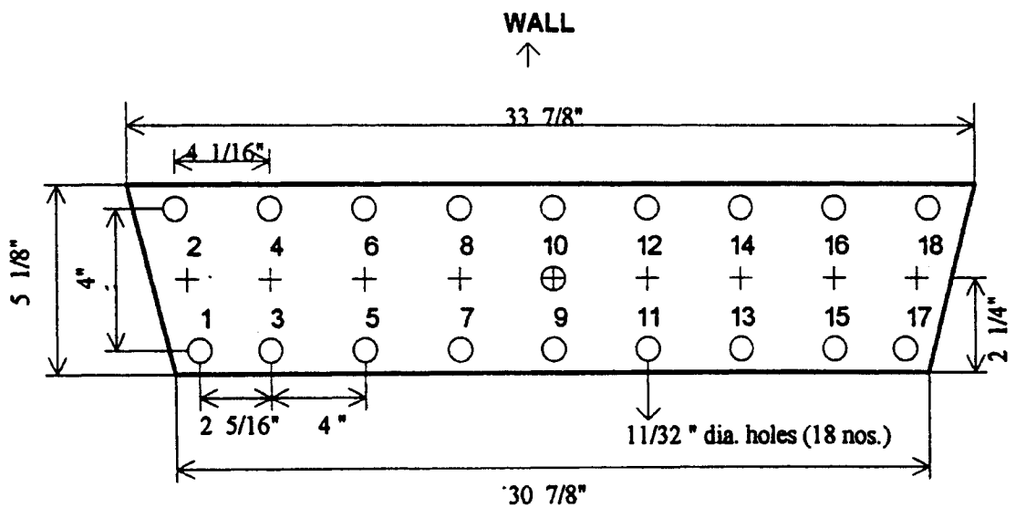


Fig. 3-4 Plan of distributor trough

coefficient and also to observe and measure distribution patterns. It measured 33 7/8 inches(86.04 cm.) long at the back, 30 7/8 inches(78.42 cm.) long in the front and had an inside width of 5 1/8 inches(13.02 cm.). It was made from a 11 gage thick(0.12 in.) sheet. The trough had eighteen holes punched in the bottom, which were used for distribution of the liquid. Each hole was nominally 11/32 inches(0.87 cm.) in diameter. Hole diameter measurements are tabulated in Appendix 3. The holes were arranged in two rows of nine holes each. Nine taps for head measurement were provided between the holes of each row as shown in Fig. 3-5. This was done in the workshop at O.S.U. Metallic nipples were soldered to each of the nine holes. Graduated vertical glass tubes were connected to the nipples using flexible tubing. These glass tubes were used to measure the liquid level inside the distributor. They were held in place by a rectangular plastic block which was fixed at the top along the length of the distributor trough. The tubes were secured by tightening plastic screws fixed to the rectangular block. Structural support was provided by angle irons fixed to the back of the trough and bolted to the wall of the room. A combination of angle irons was used such that the distributor could be leveled by adjusting the tension in the bolts. Plexiglas shields were placed around the trough to prevent water from splashing onto the floor. A 1 1/4 inch, Schedule 40 PVC pipe was used as the inlet pipe to the trough. The first series of runs was taken with the pipe positioned in the center and 8.54 inches(21.69 cm.) from the bottom of the trough. This position will be referred to as position 1. For the second series of runs, the pipe was placed in the center and 1.875inches (4.76 cm.) from the bottom. This position will be referred to as position 2.

Momentum Breaker

(Fig. 3-6) For a few runs, it was decided to break the momentum of the inlet jet using a simple weir type device, and study the results thus obtained. The device consisted of a plastic box which was designed to fit the width of the trough. It was 2 inches(5.08

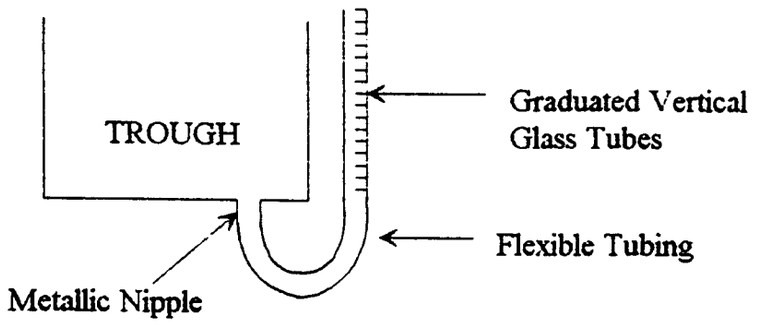


Fig. 3-5. Connection of Tubes to Trough

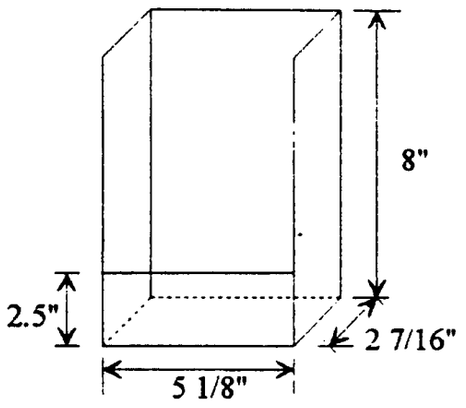
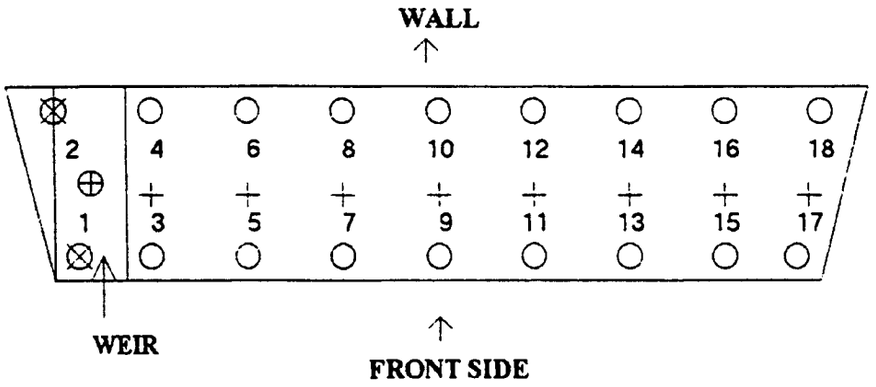


Fig. 3-6 Weir type momentum breaking device



⊕ INLET PIPE (1.653 IN. O.D, 1.577 IN. I.D) IN WEIR OF HEIGHT 2.75 IN.

+ TAP FOR HEAD MEASUREMENT (TOTAL 8 LOCATIONS)

⊠ BLOCKED HOLES

Fig. 3-7 Plan of distributor trough with momentum breaker

cm.) in length, 8 inches(20.32 cm.) high on one end and 2 inches(5.08 cm.) high on the other end. The box was placed at one end of the trough and so the inlet pipe had to be repositioned to enter at the end.(Fig 3-7) Two orifices had to be blocked with rubber plugs because the momentum breaker occupied the space above them. As the water was discharged from the pipe, the jet first struck the box, lost some of its kinetic energy and then overflowed over the 2 inch end into the trough.

CHAPTER IV

EXPERIMENTAL PROCEDURES AND DATA ANALYSIS

This chapter describes the operating procedures, precautions and troubleshooting techniques associated with the trough tests. It also gives a brief account of the equations and methods used to interpret the data obtained. The experimental procedures used for the single orifice plate tests are similar to those used for the distributor experiments because both made use of the recirculating loop. However, a few steps regarding the single orifice test apparatus will first be mentioned since they are an essential part of the experiment. Details are available.(Derasari, 1992)

Single Orifice Plate Test Facility

Plates supplied by four manufacturers were tested and the data analyzed. Reruns were carried out to check and confirm the data obtained. Most of the plates tested had 0.5 inch diameter holes. All possible combinations of parameters were examined, i.e., burr up, burr down, flow parallel to and counter to the direction of the punch; increasing and decreasing flow rates. Some of the important precautions taken are:

1) Leveling the apparatus using leveling screws.

2) Accurate measurement of the zero point in the liquid level indicator.

3) Elimination of any vortex by adjusting inlet pipe position.

4) Slow and controlled operation of the globe valve which regulates water input to

the cylinder. This was needed to avoid sudden increases or decreases in the flow rates.

The basic operation involved opening the valve in the feed line to the trough until a desired flow rate was achieved and then measuring the flow rate and liquid level at steady state. Flow rates were initially measured by collecting water in a measuring cylinder over a time interval of 20-30 seconds. Subsequently, a turbine flowmeter was used to measure the flow rate. Calibration data for the flowmeter are presented in Appendix 4. The flowmeter readings were verified from time to time by manual checks. The flow was then increased gradually, reaching a new steady state each time and the corresponding liquid levels were noted.

Trough Tests with Recirculating Loop

According to the design specifications, the trough was rated for minimum and maximum flow rates of 10 and 24 gpm respectively. Hence the 2 inch pipe pumping system was used for the experiments. The maximum head that could be read was about 7-8 inches.(17.8 - 20.3 cm.) About 1 to 2 inches(2.54 - 5.08 cm.) of the trough height was lost because the view of the liquid level was obscured by the presence of the rectangular block needed to support the level indicator tubes. This was not considered to be too much of a problem because the distributor itself was 9 3/8 inches(23.81 cm.) high. The following general operational procedures are used for conducting an experiment: (Derasari 1992)

Startup:

1) The level indicator tubes are filled with water until the first drop appears on the bottom surface inside the trough. This reading is recorded as the zero point.
2) The drain valves of the feed and constant head tank are closed. Also, the outlet valve downstream of the constant head tank is closed.

3) The feed tank is filled by opening the valve in the main water supply line.

4) The valve upstream of the pump is opened.

5) The valves in the bypass line around the pump and rotameter are opened to reduce stress on the equipment. The valve upstream of the rotameter is closed at this time.

6) The pump is started and the constant head tank is filled.

7) The bypass valve around the rotameter is gradually closed and the upstream valve simultaneously opened.

8) The flowmeter is switched on.

9) The valve downstream of the constant head tank is gradually opened until the desired flow rate is achieved.

10) The flow is allowed to stabilize until an approximate steady state is achieved. This is manifested by a more or less stable liquid level and also an approximately constant flow meter reading.

11) Once steady state is achieved, the individual orifice flow rates are measured using a measuring cylinder and stopwatch. The corresponding liquid levels in the level indicators are noted.

12) The surface of the water in the distributor is examined for any aberrations or abnormal phenomena such as local vortex formations, excessive rippling, etc. Also, the jets are checked for continuity, smoothness and straightness and qualitative observations are recorded.

13) The flow rate is changed until a new steady state is achieved.

14) Steps 10 - 14 are repeated.

Shutdown:

1) The valve in the rotameter bypass line is opened and simultaneously the ones in the main line closed.

2) The pump and flow meter are switched off.

3) The outlet valve from the constant head tank is gradually closed to avoid damaging the bearings in the flowmeter.

4) The valve upstream of the pump is closed.

5) The feed tank is drained.

6) The constant head tank is drained and the drain valve from the feed tank is closed.

Precautions:

1) Make sure the distributor is leveled before starting the experiment. Check leveling in all directions. If the distributor is not leveled, maldistribution effects will be manifested as significant variations in orifice flow rates, especially at the ends of the distributor.

2) Always open and close the outlet valve from the constant head tank slowly to prevent a sudden surge from occurring, which could damage the turbine flowmeter.

3) One needs to visually confirm the level in the distributor because, at some flow rates, the position of the inlet pipe could allow the jet impact to create severe fluctuations in the readings for the holes in the immediate vicinity. In such cases, an approximate level reading is taken. The value used is the average value for the neighboring holes.

4) Sufficient time should be allowed for the system to reach steady state.

5) At least three temperature readings should be taken at different times for each run. In these experiments, the viscosity and density were calculated at the average temperature because it was found that there weren't any significant temperature variations during each run. The maximum difference between any two temperatures recorded during an experiment was $2^{o}F$.

Data Interpretation

The measured variables in the experiments were the liquid level or head and the flow rate. The liquid level was measured in centimeters and the flow rate in cc/s. When

the flow meter was used to measure the flow rate, the readings were obtained in gpm. These readings were then converted to consistent units and used to calculate an orifice coefficient(Eqn 1-1) and a Reynolds number(Eqn. 4-1). This was done because it is believed that a more general correlation can be obtained between the orifice coefficient and the Reynolds number which can be used to determine head-flow rate relationships for any liquid with known physical properties. Further work is under way to determine whether the Reynolds number can be used as a sufficient correlating parameter for the orifice coefficient.

Besides determining the orifice coefficients for the holes in the trough, the distribution patterns were also studied. Specifically, flow and head variations from hole to hole along the length of the distributor were recorded and later analyzed as a function of inlet pipe position and overall flow rate. Predictions of the trough performance were also made using the single orifice data for holes which were comparable in geometrical configuration to the orifices in the trough. These were then compared with the actual data obtained on the distributor. Also, the angle of discharge was measured for each of the jets.

The orifice Reynolds number and the orifice coefficient are defined as follows:

Orifice Reynolds Number: (Re)

This parameter is defined by the following equation:

$Re = dv\rho/\mu$ .....(4-1)

where,

d = hole diameter, m or ft

v = velocity of water through the orifice assuming constant flow, m/s or ft/s

ρ = density of the liquid, kg/m^3 or lb_m/ft^3

μ = viscosity of the liquid, kg/m-s or lb_m/ft-s

The density of water was obtained from Perry(1988).

Orifice Coefficient: (C_o)

The orifice coefficient is calculated using Eqn 1-1.

$v = C_o(2gh)^{1/2}$ .....(1-1)

where,

g = gravitational acceleration, m/s^2 or ft/s^2

h = height of liquid above the orifice, m or ft

The derivation of this equation is presented in Appendix 5. It is similar to that derived by Derasari for the single orifice case.

CHAPTER V

RESULTS AND DISCUSSION

In this chapter, the results obtained from the experiments will be presented and analyzed. The single orifice plate studies will first be discussed. As mentioned earlier, most of the plates analyzed had hole diameters of 0.5 inches. Plates supplied by four different manufacturers were tested. The results for these plates will be compared with those obtained by Derasari. The effect of various parameters like plate thickness, presence of burrs, direction of punch and hysteresis will be shown.

One of the objectives was to determine whether it was possible to use the single orifice plate data to predict the head-flow rate relationship for the trough distributor. Using the overall inlet flow rate and an average value of the orifice coefficient obtained from the single orifice studies, some calculations will be performed to predict the average liquid head in the trough. These values will be compared with the actual values recorded. The orifice coefficient was obtained from the results for a plate comparable in hole size and plate thickness to the distributor. However since no plate had exactly the same hole diameter and plate thickness as the distributor, some interpolation was required.

The next part of this chapter will analyze any effect of hole interaction in the trough tests. A comparison will be made between the results(orifice coefficients) obtained using the trough tests and the results predicted using the single orifice plate data. After this, liquid flow and head distribution among the holes in the distributor trough for various inlet

flow rates and inlet pipe positions will be discussed. The coefficients of variation, i.e., C_V values, will be presented for the flow rates through the distributor orifices. These will be compared with standard values of C_V reported in the literature. A graphical representation of the relationship between the average flow rate through each orifice and the average head developed over each orifice will be shown. Finally, some qualitative observations recorded during the experiments will be discussed.

Single Orifice Plate Data

The data were analyzed in terms of head vs. flow rate, head vs. orifice coefficient and orifice coefficient vs. Reynolds number. It was deemed desirable to analyze the data in terms of head vs. orifice coefficient because results from other experiments in the project seemed to indicate that the Reynolds number was not a sufficient correlating parameter to describe the orifice coefficient. All the single orifice plate data collected in this study are tabulated in Appendix 6.

Comparison of Results and Effect of Manufacturing Tolerances: Some of the runs performed by Derasari were repeated in this work to check the reproducibility of the data. Fig 5-1 shows the comparison for Plate A07ND. The results from this work are consistent with those obtained by Derasari. Fig. 5-2 shows the head -flow rate relationship for similar plates supplied by different manufacturers. It can also be seen from Derasari's results on Plate A05ND that below a head of 1 in.(~2-3 cm), the behavior is erratic and not entirely predictable. However as mentioned earlier, in this work, very few data points were taken at heads below 2 in.(4-5 cm), because it was felt that the focus should be on heads which were actually used in practice. The orifice coefficient - head relationship is shown in Fig. 5-3. Fig.5-4 shows the orifice coefficient plotted as a function of Reynolds number. It would appear from the graphs that manufacturing tolerances do not affect this

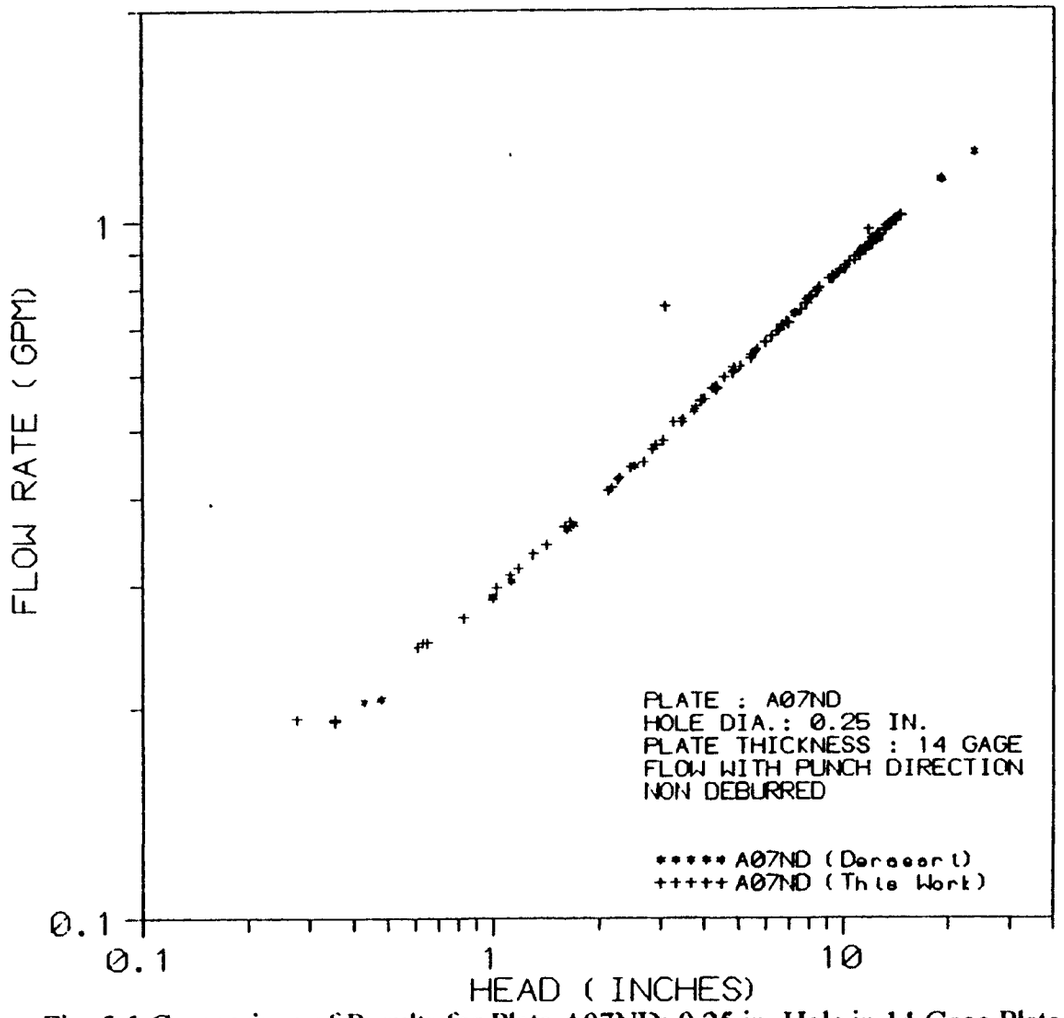


Fig. 5-1 Comparison of Results for Plate A07ND; 0.25 in. Hole in 14 Gage Plate (Flow Rate vs. Head)

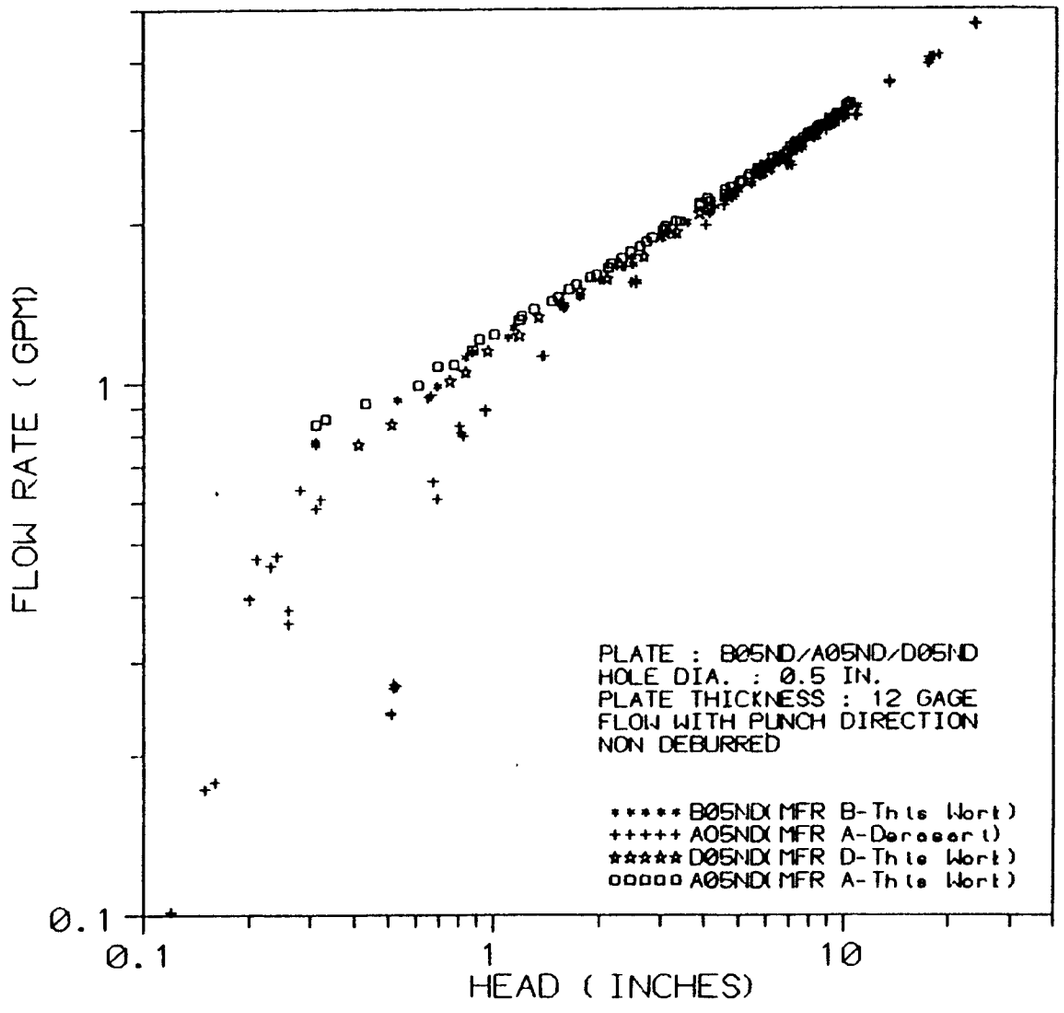


Fig. 5-2 Results for Orifice Plates from Different Manufacturers; 0.5 in. Hole in 12 Gage Plate (Flow Rate vs.Head)

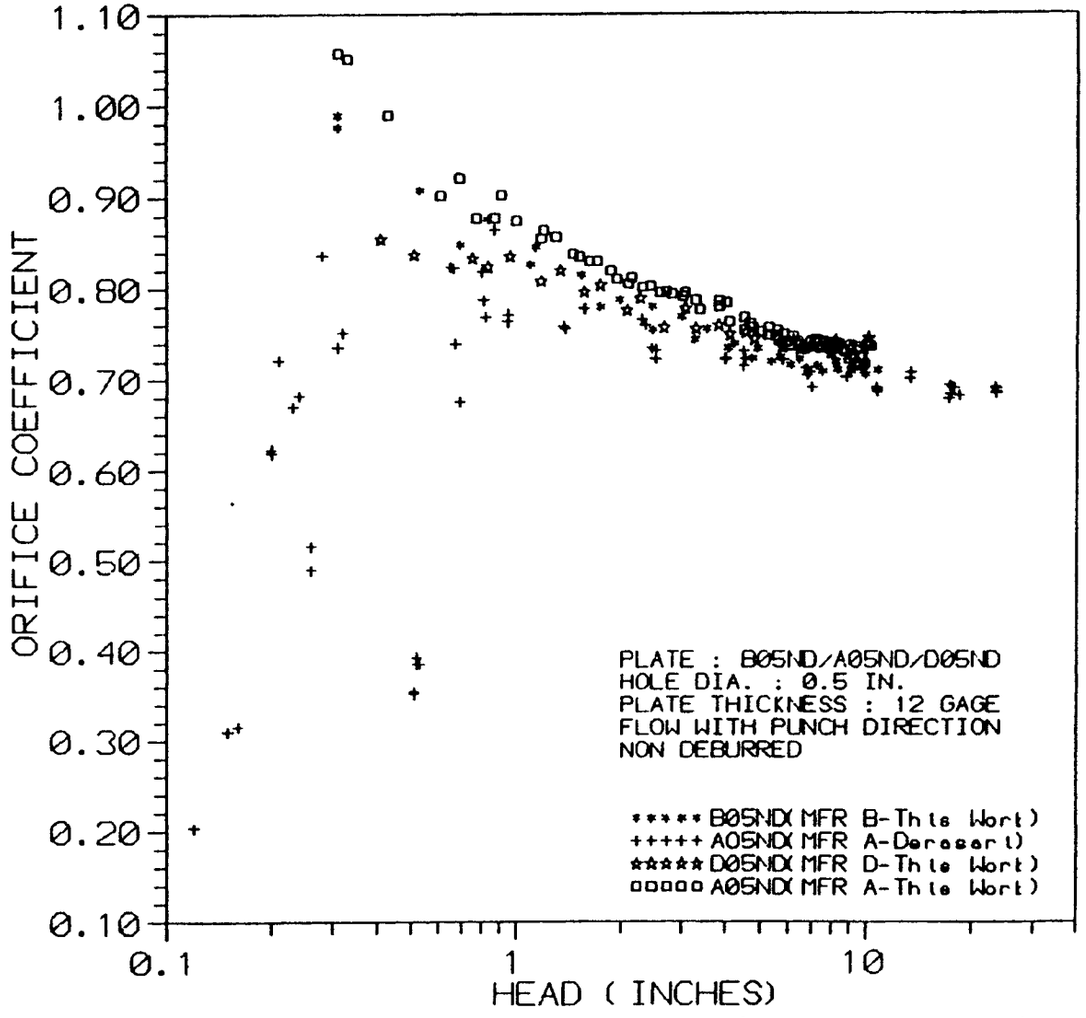


Fig. 5-3 Results for Orifice Plates from Different Manufacturers; 0.5 in. Hole in 12 Gage Plate (C_o vs. Head)

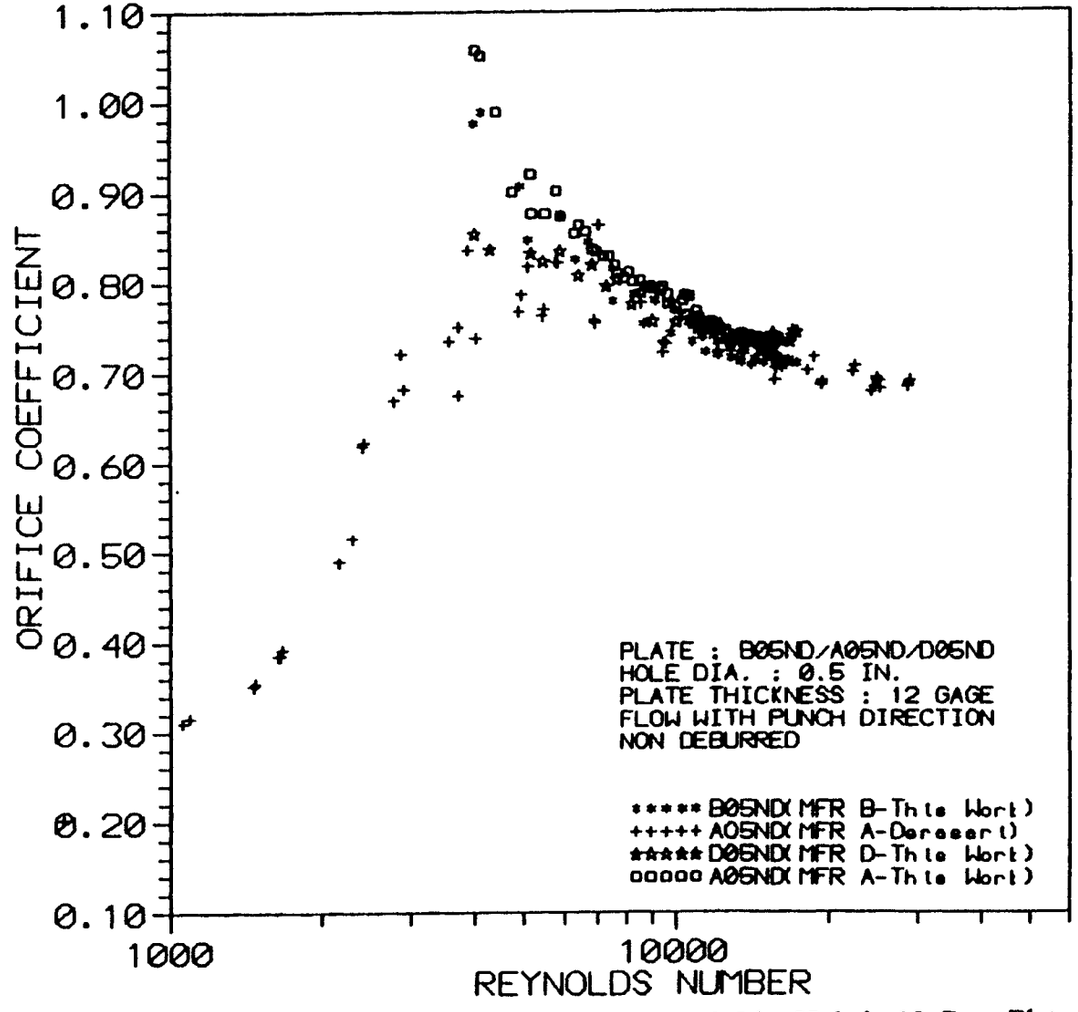


Fig. 5-4 Effect of Manufacturing Tolerances; 0.5 in. Hole in 12 Gage Plate (Orifice Coefficient vs. Reynolds Number.)

relationship significantly. Hence, results obtained from one plate of a specified hole diameter and thickness can be considered to be indicative of that particular type of plate. Fig 5-5 confirms this statement. It presents the results obtained for 0.5 in. diameter orifices in 14 gage plates.

Effect of Plate Thickness: The results obtained in this study cannot conclusively provide evidence of any plate thickness effects because only two thicknesses were considered, viz. 12 gage and 14 gage. No significant difference was observed in the results, as shown in Fig.5-6.

Effect of Punch Direction: Fig. 5-7 shows the head - flow rate relationship for a 0.5 in. diameter orifice in a 12 gage plate. Here again, there is no appreciable difference between flow counter to and flow parallel to the punch direction. The values of orifice coefficients obtained also do not seem to differ as shown in Fig. 5-8. A possible reason for this is because the plates tested were not thick enough to show any real variation due to flow orientation. If thicker plates were tested then flow parallel to the punch direction would have converging stream lines and flow counter to the punch direction would have divergent streamlines. This would alter the velocity profile which would have an effect on the orifice coefficient. Also, for parallel flow, due to the rounding of the orifice edges, the diameter of the jet increases and hence the value of the orifice coefficient may increase.

Effect of Presence of Burrs: Fig. 5-9 shows the results obtained for a deburred and a non deburred plate. It can be seen that for a fixed head, a slightly higher flow rate is obtained using a deburred plate. In the orifice coefficient-head graph, (5-10) this translates into higher orifice coefficients for the deburred plate. A possible explanation for this could be that since deburring involves the removal of a small amount of material from the flow path of the liquid, the resistance to flow is decreased and hence the flow through the hole increases. This is manifested as an increase in the orifice coefficient.

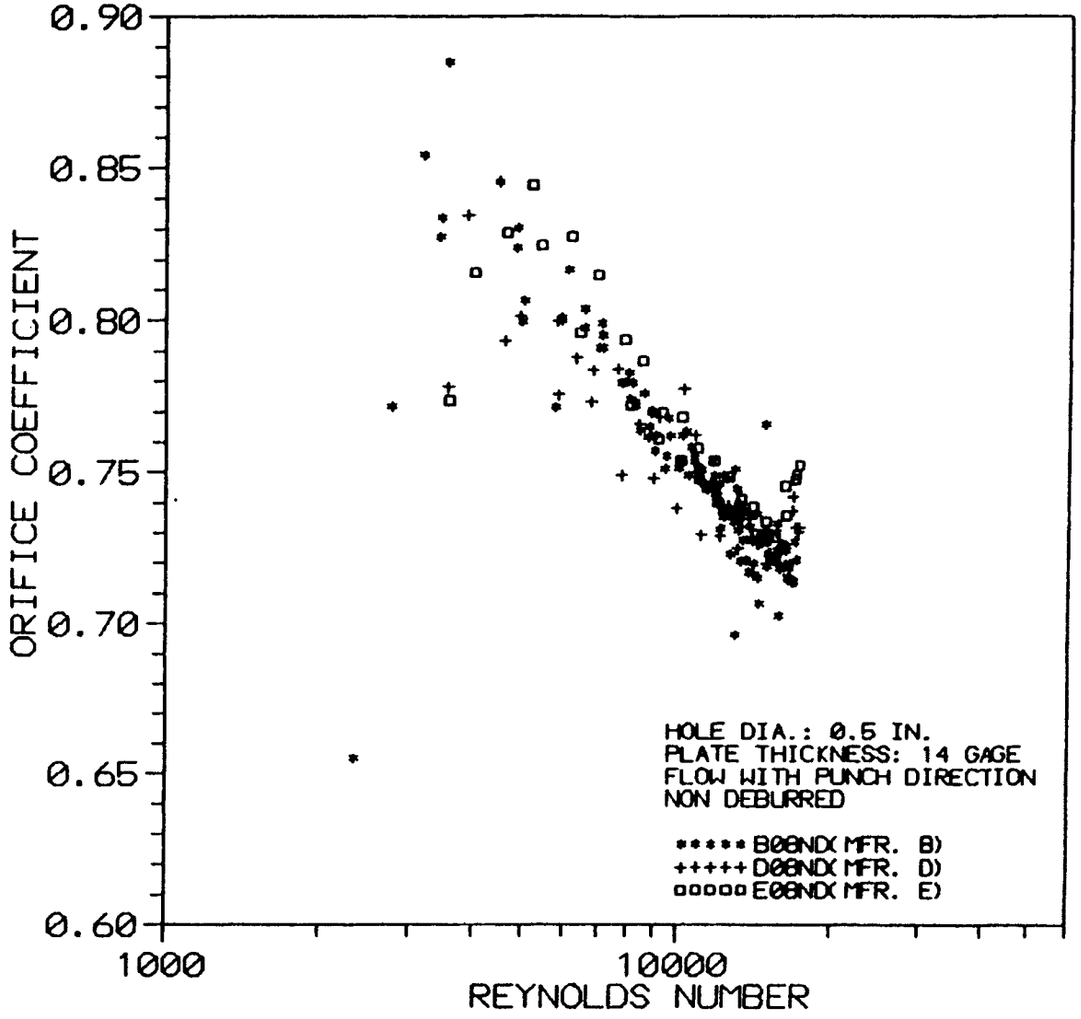


Fig. 5-5 Effect of Manufacturing Tolerances; 0.5 in. Hole in 14 Gage Plate (Orifice Coefficient vs. Reynolds Number)

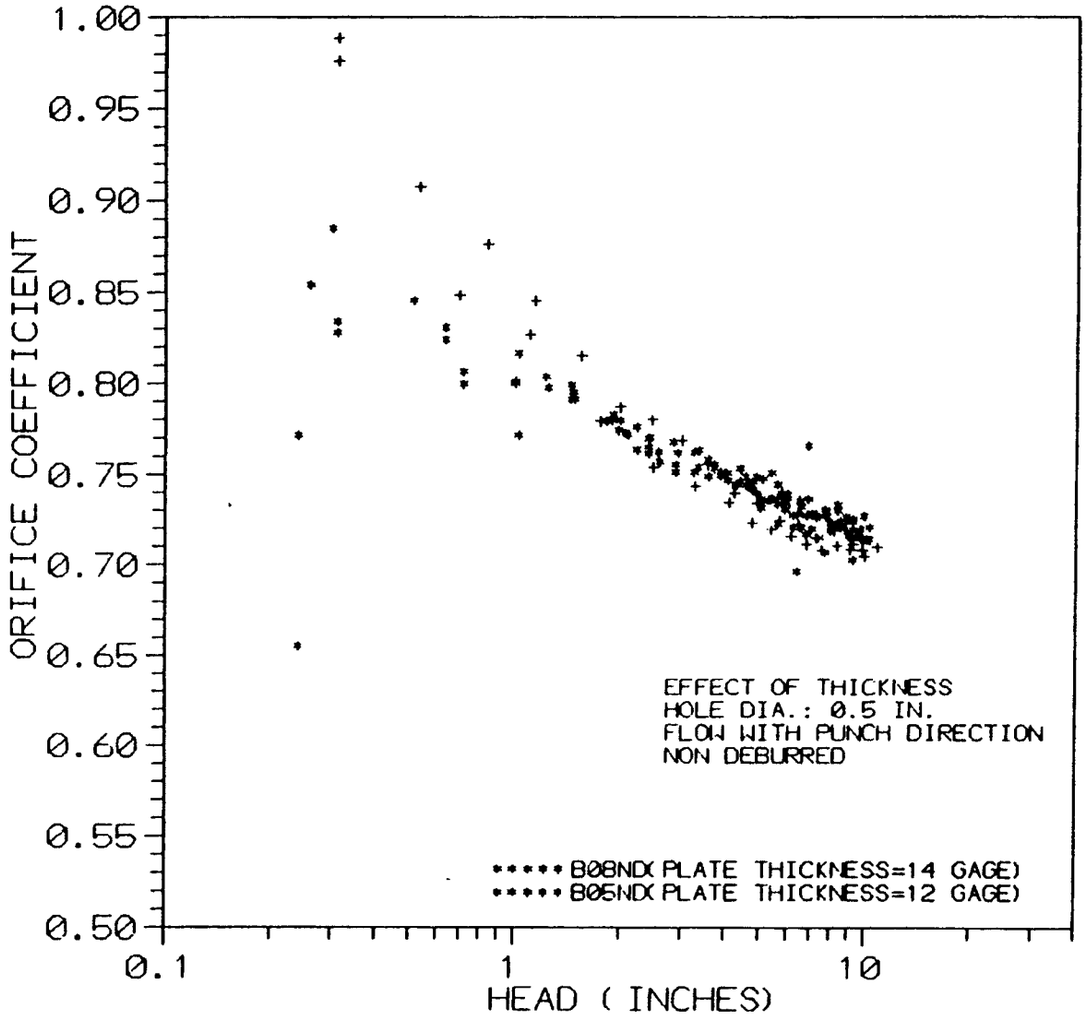


Fig. 5-6 Effect of Plate Thickness.
(C_0 vs. Head)

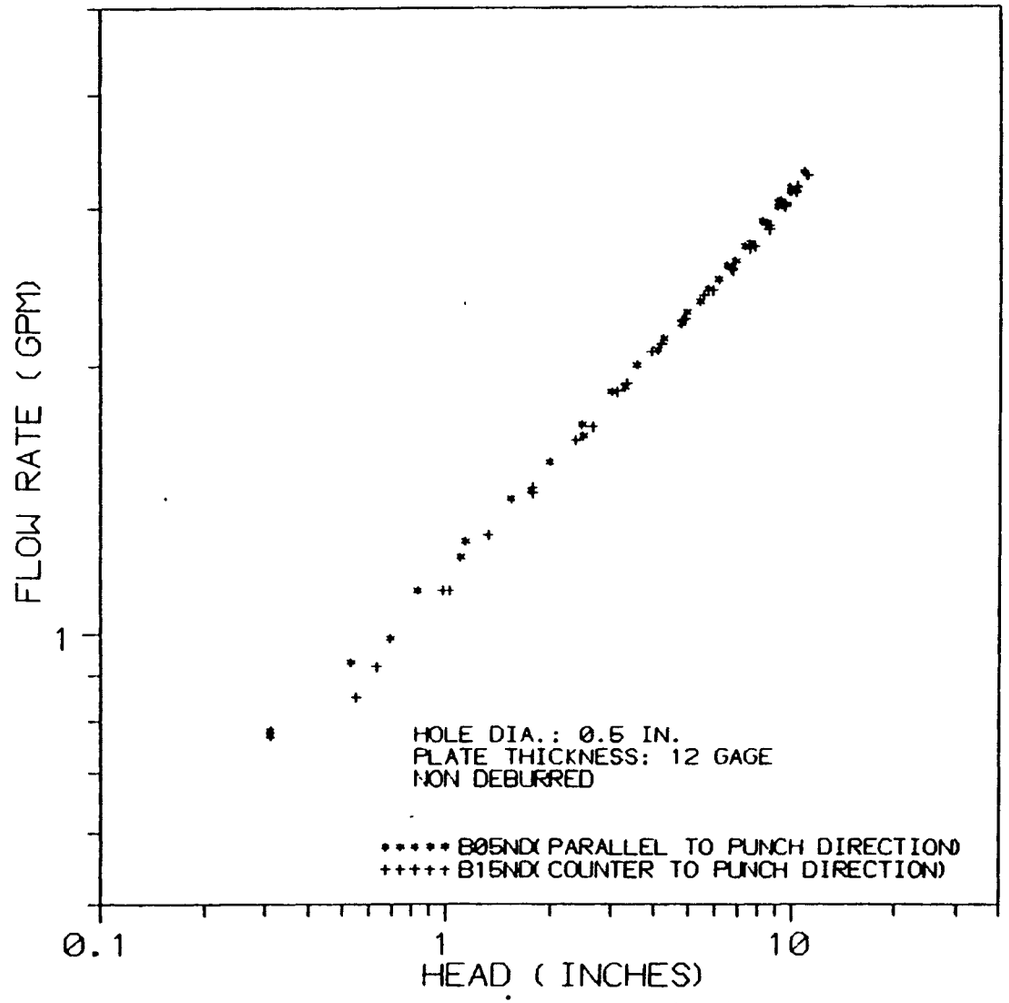


Fig. 5-7 Effect of Punch Direction.
(Flow Rate vs.Head)

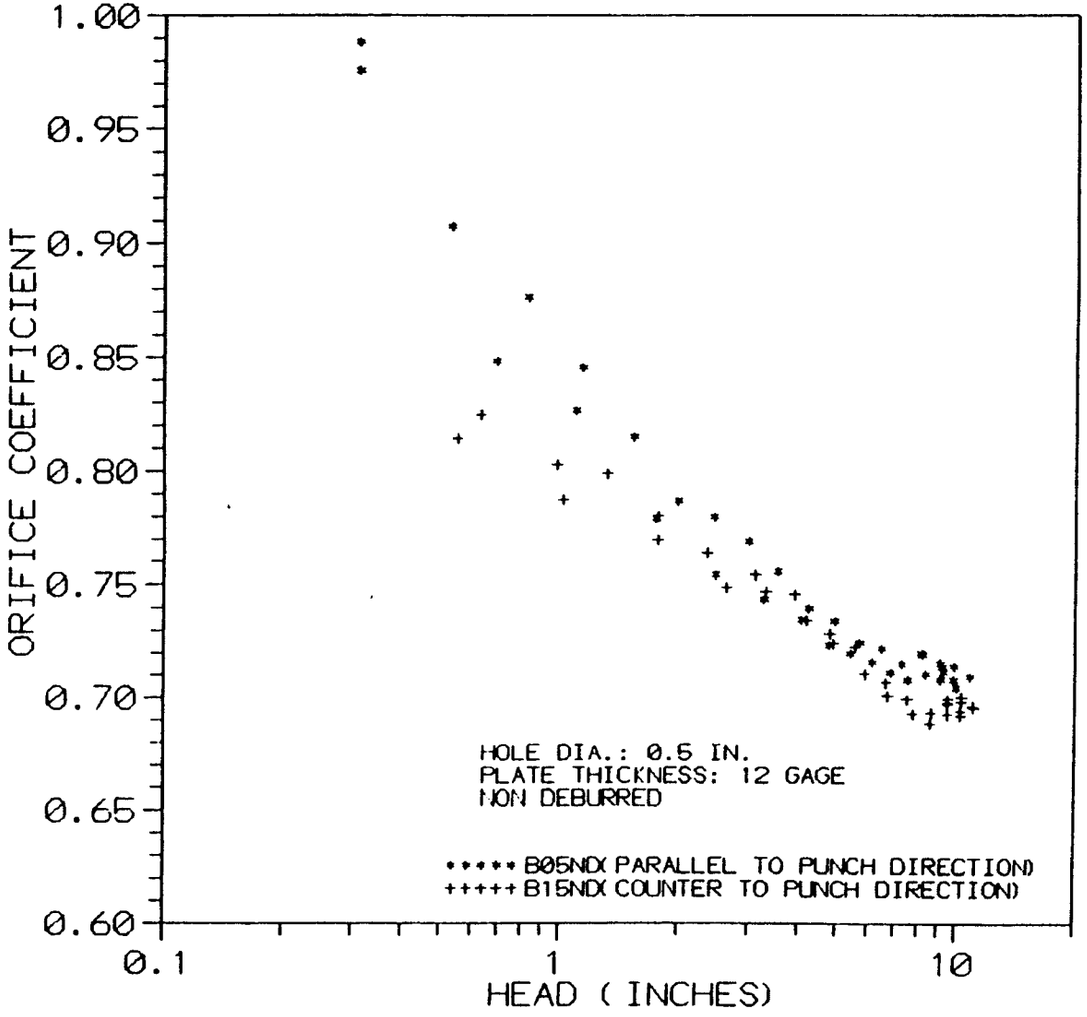


Fig. 5-8 Effect of Punch Direction.
(C_o vs. Head)

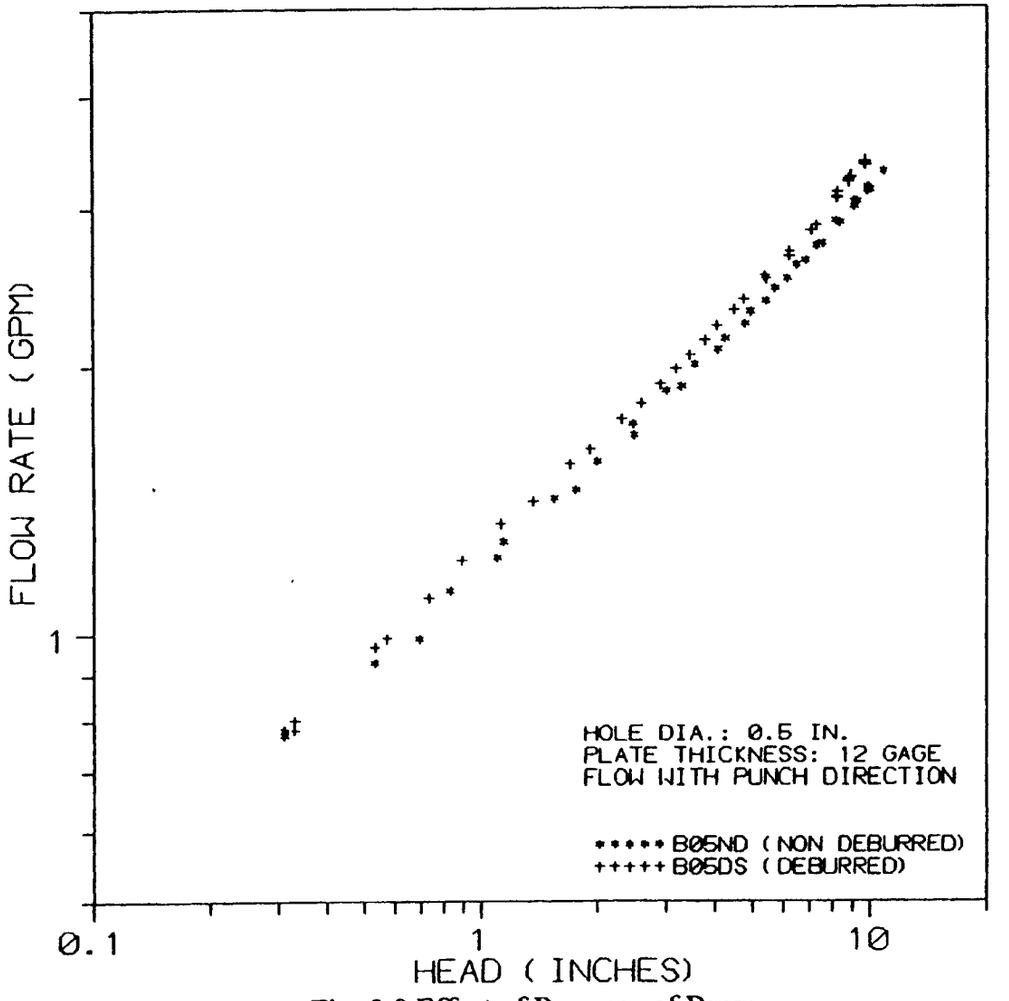


Fig. 5-9 Effect of Presence of Burrs.
(Flow Rate vs.Head)

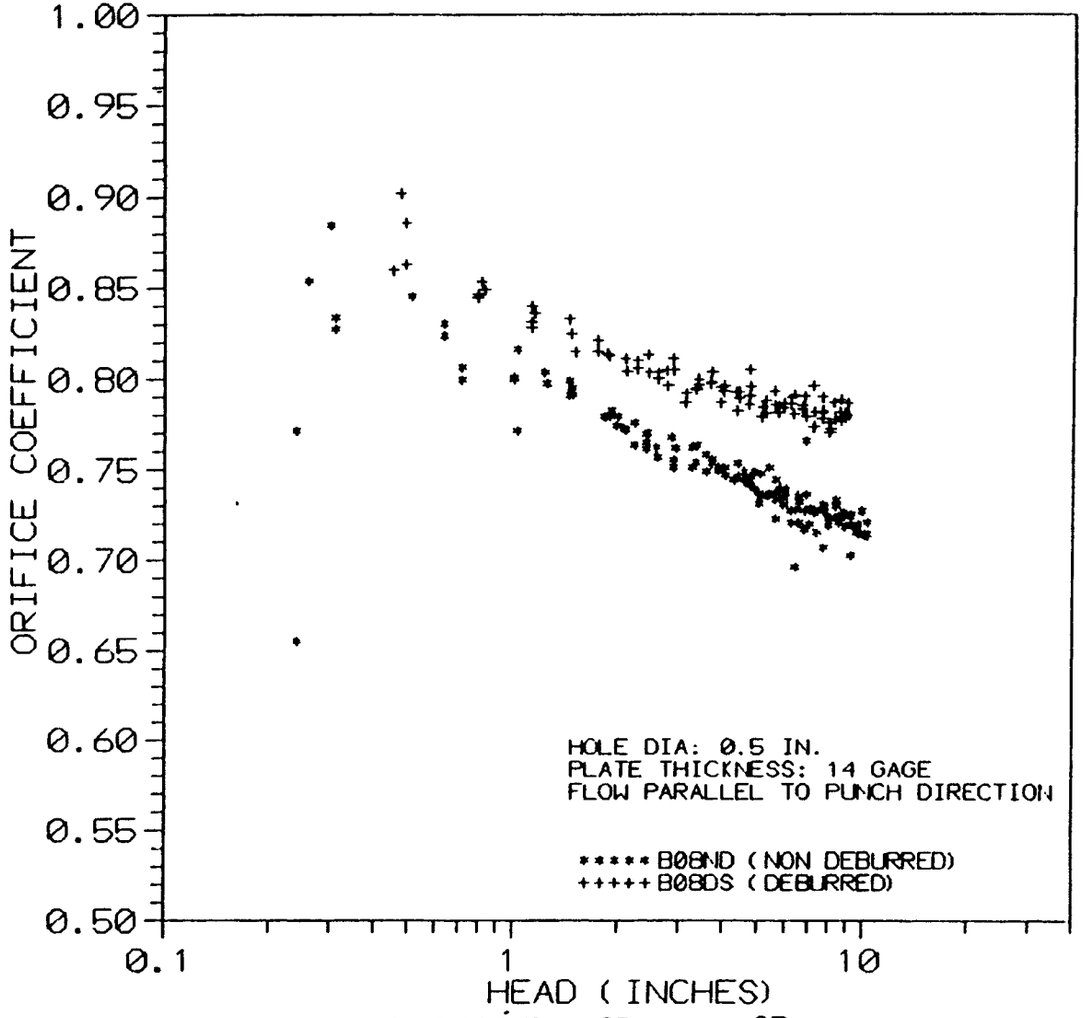


Fig. 5-10 Effect of Presence of Burrs.
(C_o vs. Head)

TROUGH TESTS

A total of 28 runs were performed on the distributor trough. Of these runs 1-3 are not documented in this work, because they were trial runs carried out to familiarize ourselves with the equipment. All the other data are presented here in Appendix 7. The parameters measured were the head in cm, and the flow rate in ml/sec. The flow rates were converted to gpm, and orifice coefficient and Reynolds number values were calculated.

A Priori Prediction of Distributor Trough Performance: One of the objectives in this study was to check whether the head - flow rate relationship could be predicted using the data obtained from a single orifice plate study. To do this, we selected a value of an orifice coefficient based on the results obtained for 12 gage thickness plates corresponding to hole diameters of 0.25 in. and 0.5 in.(A04ND and A05ND). These plates were chosen because they came closest to approximating the distributor thickness of 11 gage and the orifice diameter of 11/32 in. The orifice coefficient thus obtained was 0.78. The details of the calculations and data reduction are shown in Appendix 8. Table 5-1 shows a comparison of the results obtained. From the table we see that the predictions are fairly close for flow rates between 8 and 18 gpm. However, below 8 gpm and above 18 gpm, the percentage difference is quite significant. This is expected, because from the plots of orifice coefficient vs. head used for finding the orifice coefficient, one can see that at very low heads(< 1 in.), the flow was very unpredictable and at high heads(> 10 in.), the orifice coefficient asymptotically approached a constant value. These heads corresponded to overall inlet flow rates less than 8 gpm. and more than 18 gpm respectively. Hence, the value of the orifice coefficient used, could not be considered as representative of these regions and so the predictions are not as good.. Thus, it would be reasonable to assume that one can predict the performance of the distributor with reasonable accuracy using one

TABLE 5-1

COMPARISON OF PREDICTED AND OBSERVED HEAD IN THE DISTRIBUTOR TROUGH

RUN #	TOTAL FLOW RATE GPM	PREDICTED HEAD, CM A	OBSERVED HEAD, CM B	PERCENT DIFFERENCE 100*(A-B)/A
4	10.37	3.09	2.84	8.09
5	14.66	6.18	6.15	0.42
6	12.55	4.53	4.24	6.34
7	16.61	7.92	8.06	-1.71
8	18.74	10.09	10.5	-4.03
9	20.65	12.26	13.04	-6.40
10	23.07	15.30	16.75	-9.50
11	24.51	17.27	19.19	-11.12
12	24.51	17.26	19.05	-10.36
13	7.57	1.65	1.54	6.50
14	5.75	0.95	0.79	16.77
15	6.06	1.05	0.81	23.21
16	8.20	1.93	1.61	16.65
17	10.27	3.03	2.73	9.91
18	12.38	4.40	3.9	11.45
19	14.49	6.03	5.71	5.38
20	16.55	7.87	7.7	2.18
21	18.42	9.75	10.14	-4.03
22	20.66	12.27	13.28	-8.27
23	22.51	14.56	16.14	-10.88
24	24.18	16.80	19.03	-13.31
25	6.21	1.11	0.82	25.91
26	12.94	6.09	5.51	9.54
27	18.31	12.20	12.81	-4.99
28	21.65	17.04	19.09	-12.01

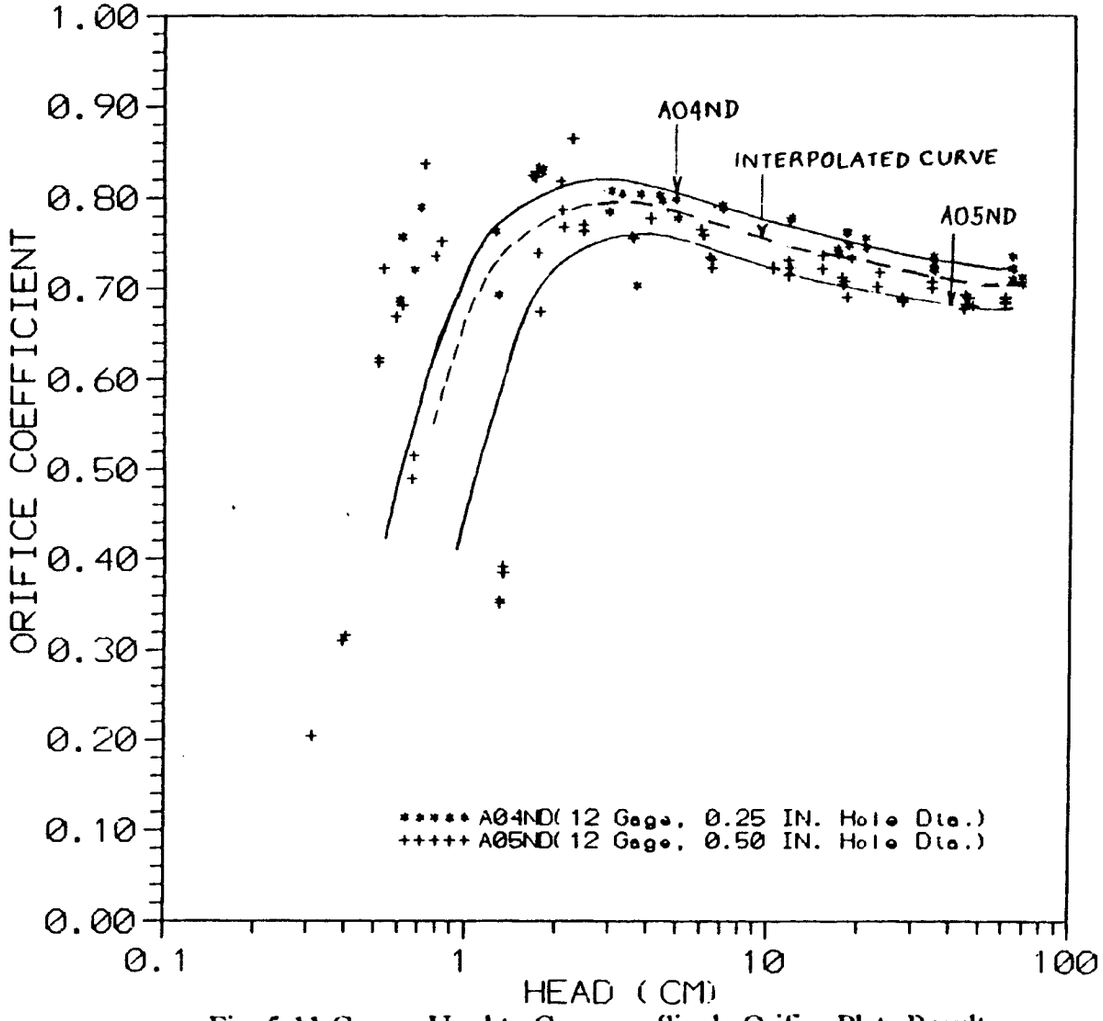


Fig. 5-11 Curves Used to Compare Single Orifice Plate Results With Trough Results.(C_o vs. Head)

value of an orifice coefficient obtained from single orifice plate data over only a limited range of flow rates. One could though, use different values of orifice coefficients for different flow regions to get better predictions. For example, an orifice coefficient lower than 0.78 could be used for flow rates greater than 18 gpm.

Comparison of Orifice Coefficient Values: The orifice coefficients obtained from the trough tests were compared to those obtained using the aforementioned single orifice plates. This would give us an indication whether the presence of other orifices around a single orifice had any effect on the orifice coefficients obtained. Any hole interaction could then be analyzed. The graph of Co vs. Head for the two plates is shown in Fig. 5-11. Some interpolation had to be done to obtain values for a 11/32 in. hole size. Table 5-2 shows a comparison of predicted and actual orifice coefficients. It is evident from the table that there is not much difference between the predicted and the observed values for heads greater than 2.5 cm.(1 inch). However for heads less than an inch, the predictions totally fall apart. Incidentally the heads less than an inch corresponded to Re<5000. Thus, it can be concluded that for heads greater than 1 inch, there is no significant interaction between orifices. Hence the orifice coefficient values obtained using the single orifice plates can be considered to be an approximate representation of the orifice coefficients for a distributor trough having the same thickness as the plate and having holes of the same diameter. An error analysis for experimental technique is presented in Appendix 9. The orifice coefficient data obtained in these experiments lie within the experimental error range as shown in Figs A9-1 and A9-2.

Effect of Inlet Pipe Position: The graphs of head vs. flow rate, C_O vs. Re and C_O vs. head for the trough are presented in Figs. 5-12, 5-13 & 5-14. These are average individual orifice values. It is observed that the position of the inlet pipe does not have

TABLE 5-2

COMPARISON OF PREDICTED AND ACTUAL ORIFICE COEFFICIENT VALUES

RUN #	AVERAGE REYNOLDS NUMBER (TROUGH)	AVERAGE HEAD IN TROUGH CM.	PREDICTED ORIFICE COEFF. (FIG. 5-7) A	ACTUAL ORIFICE COEFFICIENT B	PERCENT DIFFERENCE 100*(A-B)/A
4	5394	2.84	0.805	0.804	0.12
5	7800	6.15	0.785	0.777	1.02
6	6692	4.24	0.790	0.803	-1.63
7	8931	8.06	0.765	0.768	-0.41
8	10065	10.50	0.760	0.759	0.20
9	11042	13.04	0.740	0.748	-1.11
10	12195	16.75	0.730	0.738	-1.04
11	13189	19.19	0.720	0.732	-1.69
12	13172	19.05	0.720	0.735	-2.04
13	4188	1.54	0.750	0.882	-17.61
14	3128	0.79	0.690	0.930	-34.81
15	3369	0.81	0.690	1.010	-46.42
16	4501	1.61	0.750	0.856	-14.07
17	5786	2.73	0.795	0.813	-2.21
18	6884	3.90	0.800	0.820	-2.55
19	8059	5.71	0.795	0.790	0.58
20	9204	7.70	0.770	0.780	-1.34
21	10176	10.14	0.760	0.757	0.43
22	11366	13.28	0.740	0.742	-0.23
23	12382	16.14	0.725	0.733	-1.09
24	13386	19.03	0.720	0.725	-0.69
25	3866	0.82	0.690	1.061	-53.83
26	7815	5.51	0.795	0.812	-2.09
27	11238	12.81	0.740	0.753	-1.78
28	13253	19.09	0.720	0.729	-1.26

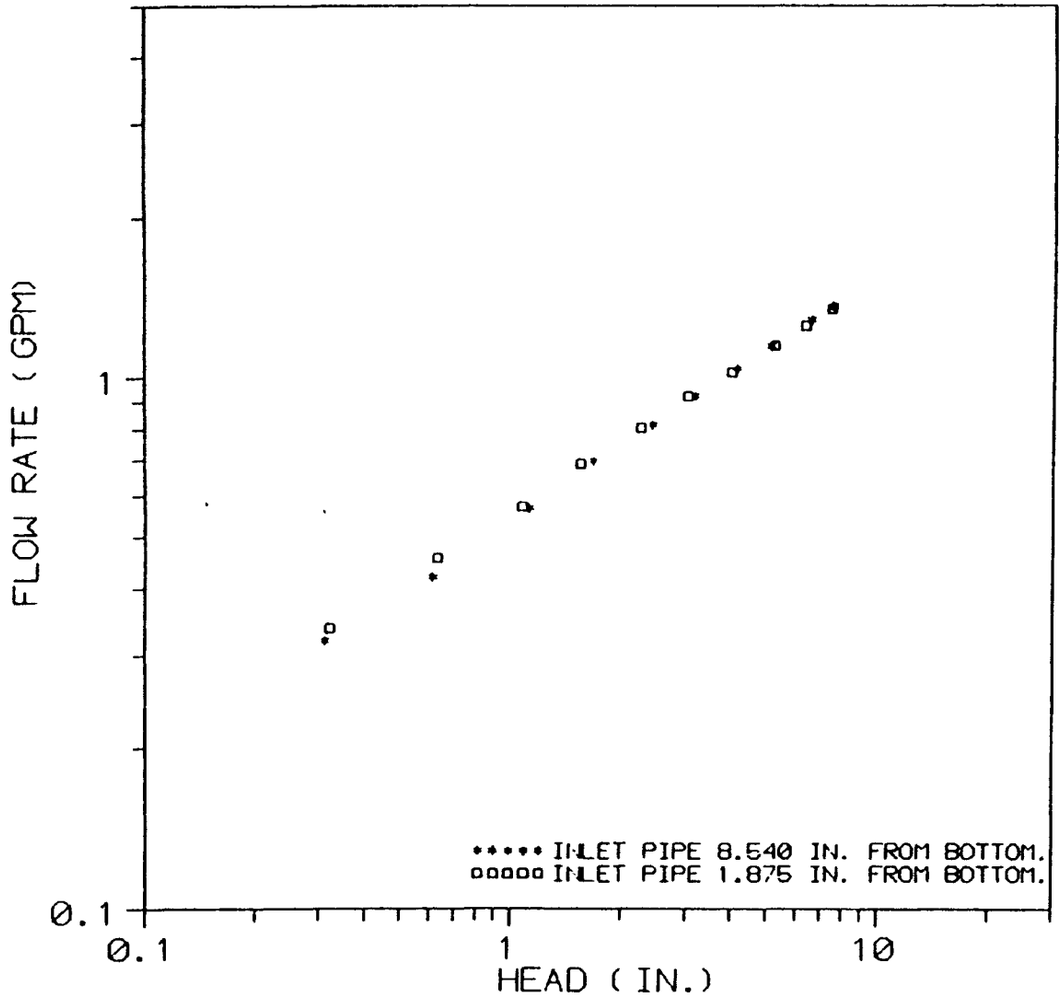


Fig. 5-12 Effect of Inlet Pipe Position
(Flow Rate vs.Head)

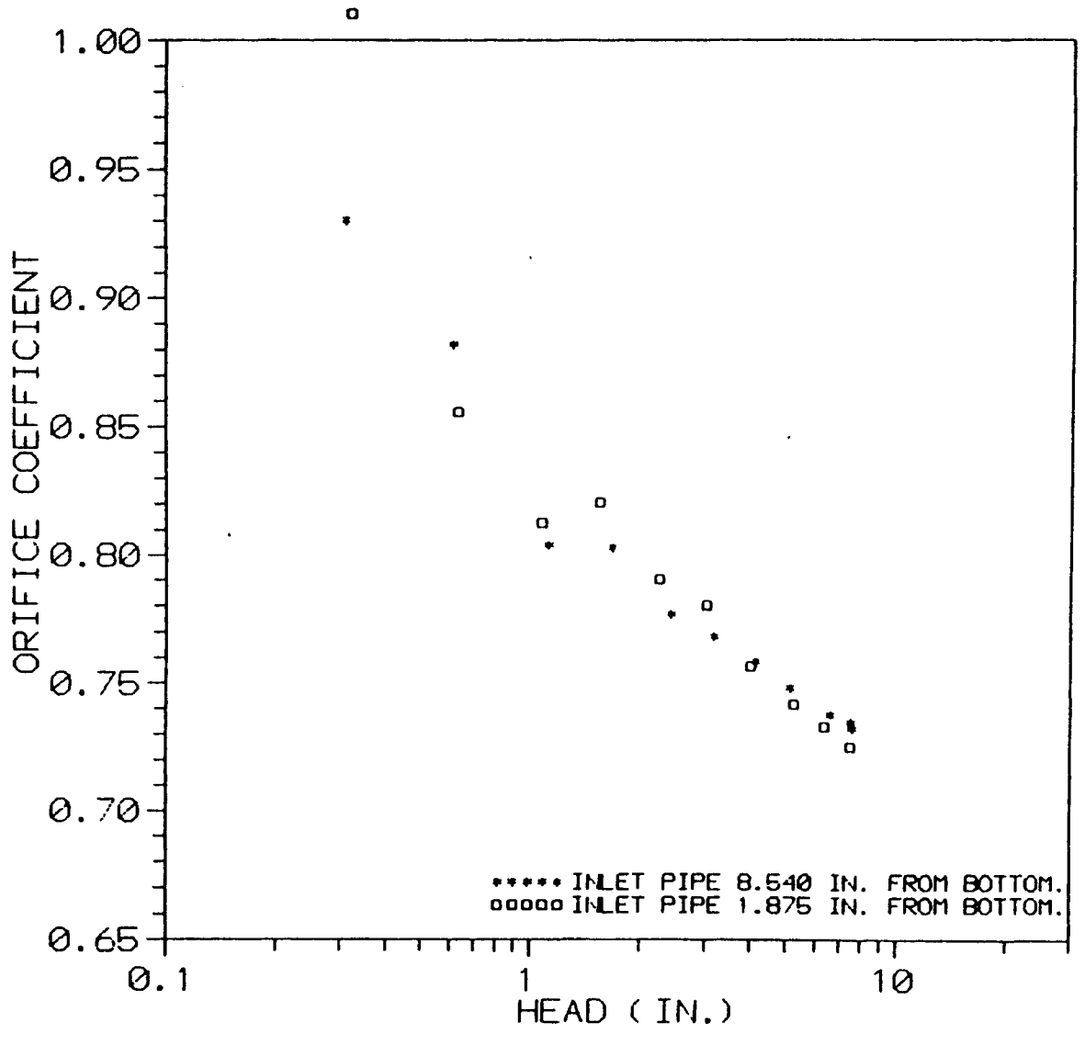


Fig. 5-13 Effect of Inlet Pipe Position
(C_o vs. Head)

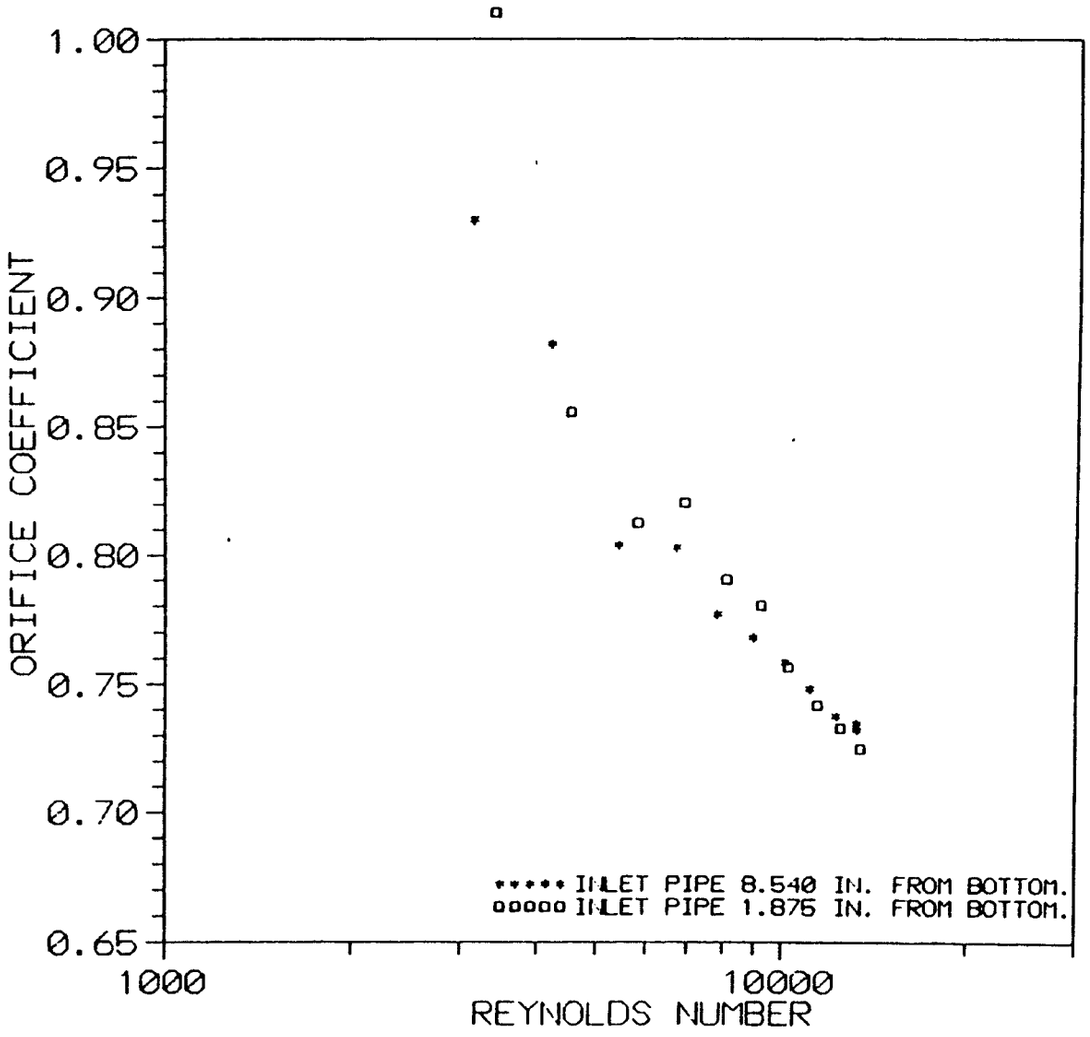


Fig. 5-14 Effect of Inlet Pipe Position.
(C_o vs. Re)

any significant effect on the results obtained. This means that even if the inlet pipe is submerged(most runs for Position 2), the distribution obtained is not much better. Fig. 5-15 shows the relationship between the overall flow rate and the head developed in the trough.

Flow Distribution in the Trough: One of the other important objectives of the trough tests was to observe and statistically measure distribution patterns. One of the ways in which this was done was by calculating a coefficient of variation(C_V) for the flows through the orifices in the distributor trough. The coefficient of variation is the percentage ratio of the standard deviation to the mean. This was done for all three positions of the inlet pipe. A low value of C_V implies good distribution, while a high value would be indicative of maldistribution. Perry et al.(1990) cite a normal range of 3-30% for the C_V and recommend a commercial value of 10%. The results are summarized in Table 5-3 and Figs. 5-16 & 5-17. The following conclusions can be drawn :

- For inlet flow rates above 12 gpm, the distribution is reasonably good. The maximum value of C_V for this flow regime was found to be 10.38 %. This inlet flow rate(12 gpm) also corresponds to a liquid head in the trough of about 2 in. This is in agreement with our initial minimum operating condition of 2 in. or 5 cm.

- For flow rates below 12 gpm, the distribution deteriorates progressively and at about 5 gpm, which corresponds to a liquid head of about 0.3 in., it completely breaks down. This is evident because C_V values of greater than 20% are observed. This was also qualitatively recorded during the experiments. Maldistribution was manifested as severe lateral dispersion of the streams and negligible flow through the orifices directly below the inlet. A more detailed qualitative description of observed maldistribution is presented later.

- The momentum breaker apparently improves the distribution to some extent. Table 5-4 shows a comparison of C_V values with and without the momentum breaker for the 12 , 18, and 22 gpm runs. It should be noted however that when the momentum breaker was used the inlet pipe entered at one end of the trough and not at the center as

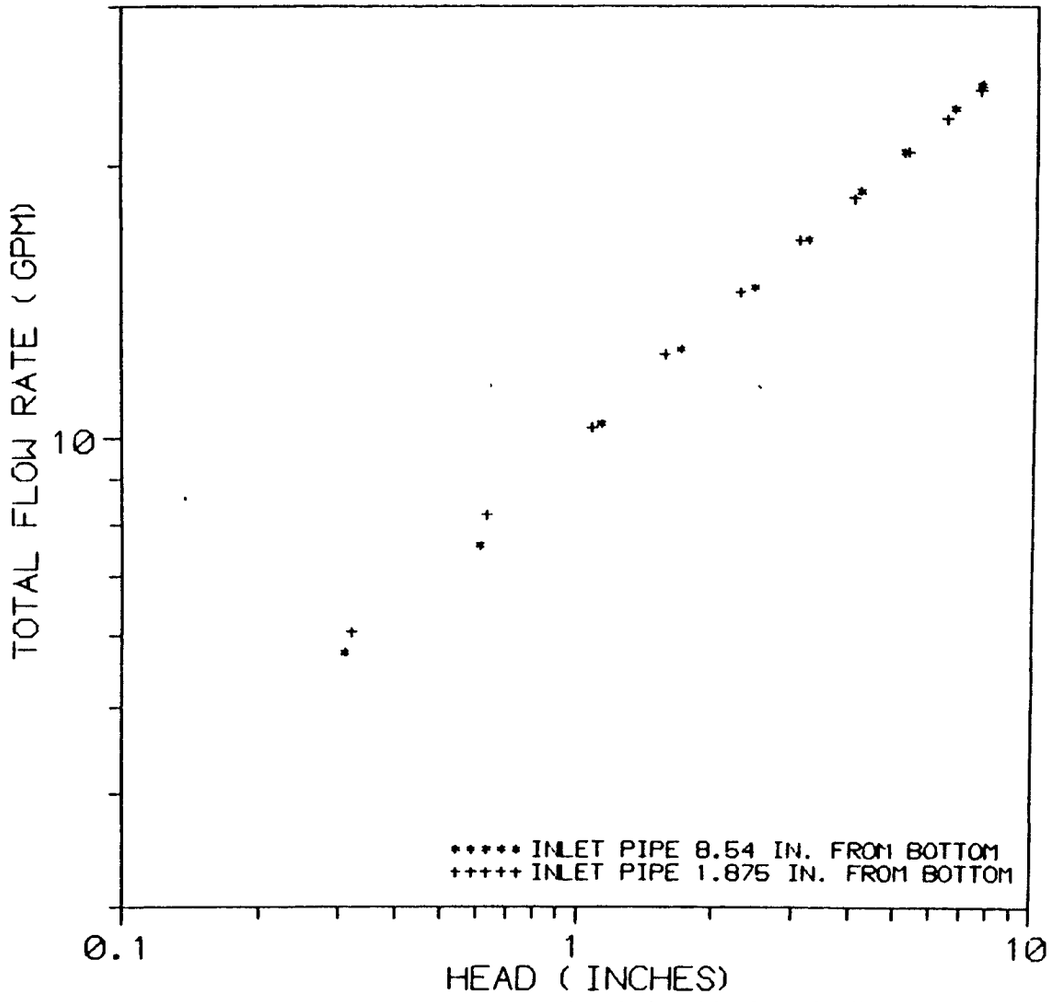


Fig. 5-15 Total Flow Rate vs. Head Relationship for Distributor Trough.

TABLE 5-3

COEFFICIENTS OF VARIATION FOR FLOW THROUGH DISTRIBUTOR ORIFICES

RUN #	TOTAL INLET FLOW RATE GPM	AVG. FLOW RATE THROUGH EACH ORIFICE, GPM (A)	STD DEV (B)	Cv 100*(B/A)
	INLET PIPE POSITION 1 - 8.54 in FROM TROUGH BOTTOM			
4	10.3741	0.576	0.116	20.16
5	14.6598	0.814	0.072	8.82
6	12.5516	0.697	0.072	10.38
7	16.6062	0.923	0.065	7.00
8	18.7416	1.041	0.046	4.43
9	20.652	1.147	0.025	2.17
10	23.0718	1.282	0.012	0.91
11	24.5415	0.806	0.035	4.39
12	24.5089	1.362	0.013	0.94
13	7.5714	0.421	0.131	31.24
14	5.7466	0.319	0.127	39.89
	INLET PIPE POSITION 2 - I.875 IN. FROM TROUGH BOTTOM			
15	6.058	0.337	0.095	28.29
16	8.1995	0.456	0.071	15.51
17	10.2688	0.554	0.091	16.38
18	12.3797	0.688	0.033	4.85
19	14.4922	0.806	0.035	4.39
20	16.5511	0.920	0.036	3.90
21	18.4171	1.023	0.033	3.22
22	20.6607	1.148	0.031	2.66
23	22.5073	1.250	0.032	2.54
24	24.1754	1.328	0.080	6.03
	RUNS USING MOMENTUM BREAKER			
25	6.2062	0.388	0.085	21.89
26	12.9405	0.809	0.011	1.32
27	18.3144	1.145	0.006	0.52
28	21.6453	1.353	0.011	0.79

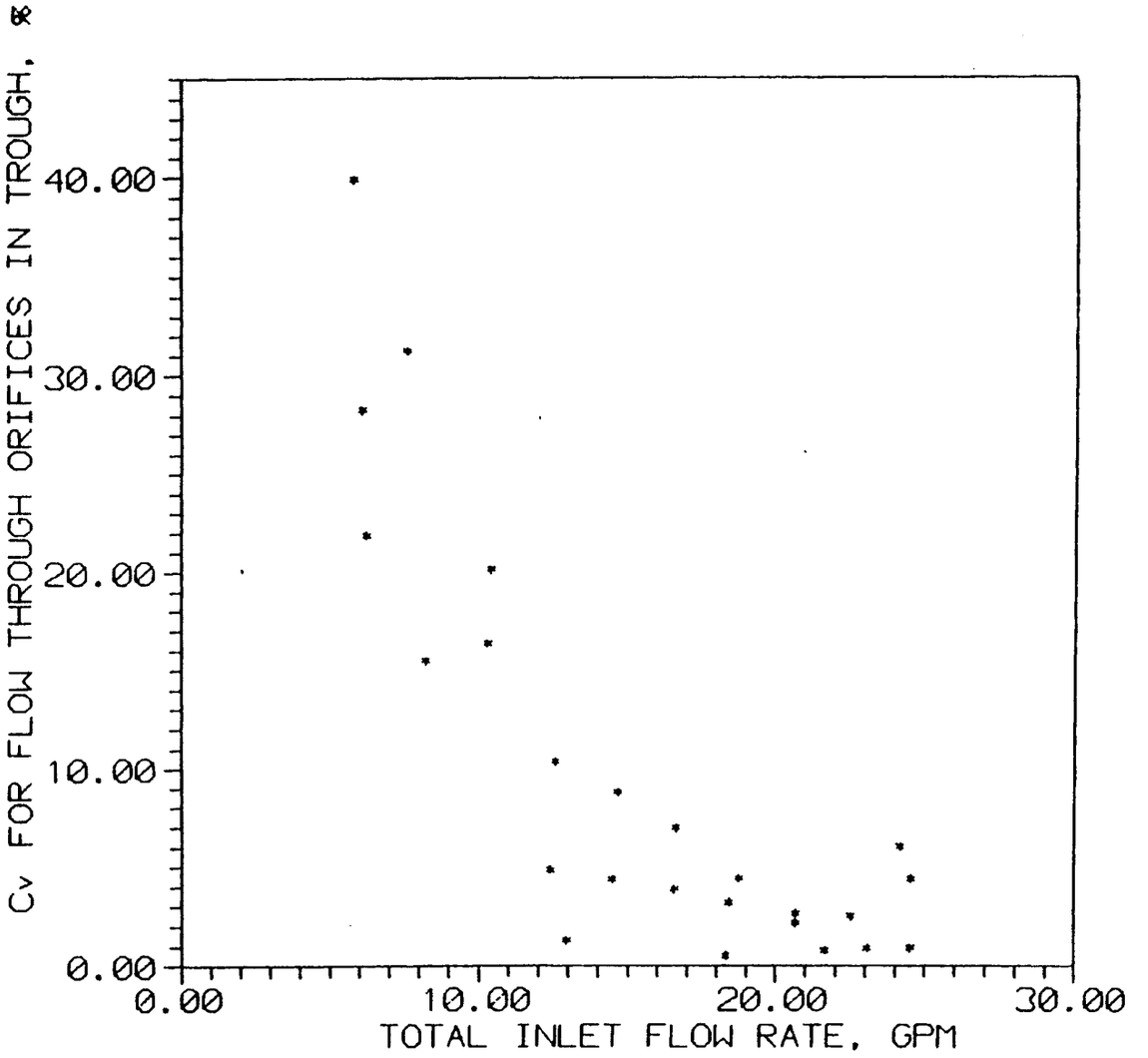


Fig. 5-16 Coefficient of Variation for Flow Through Orifices in Trough as a Function of Total Inlet Flow.

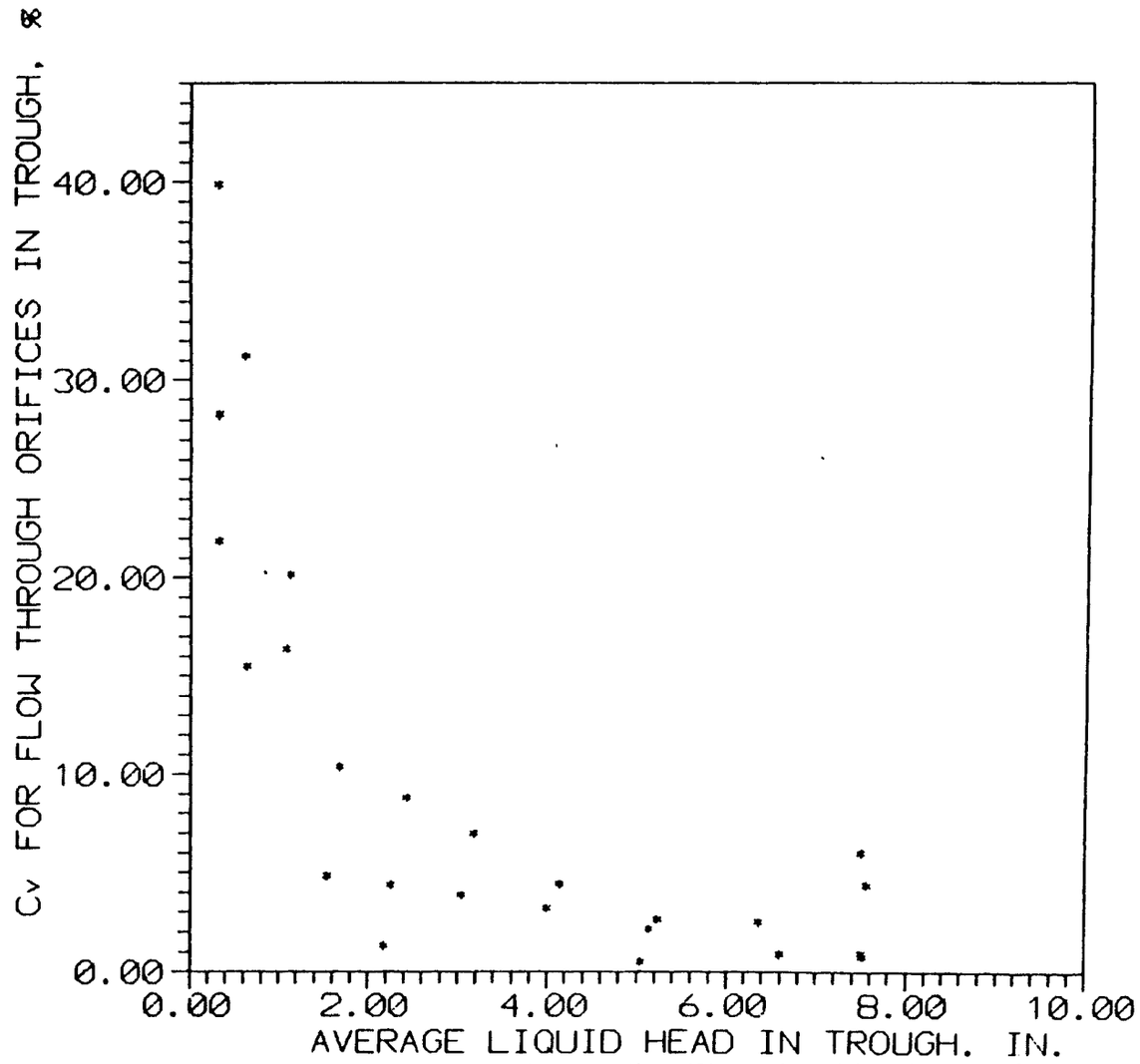


Fig. 5-17 Coefficient of Variation for Flow Through Orifices in Trough as a Function of Average Liquid Head in the Trough

was the case for the other two pipe positions. Hence no conclusive evidence can be offered for the effectiveness of the momentum breaker until tests for similar entrance conditions are conducted with and without the momentum breaker.

TABLE 5-4

COMPARISON OF Cv VALUES WITH AND WITHOUT THE MOMENTUM BREAKER

Flow Rate Gpm	Position 1 (Inlet at Center)	Position 2 (Inlet at Center)	With Breaker (Inlet at End)
12	10.38	4.85	1.32
18	4.43	3.22 (Pipe Submerged)	0.52
22	2.17	2.54 (Pipe Submerged)	0.79

A more complete description of the distribution in the trough was obtained by calculating the deviation from the mean flow rate for each orifice. The results so obtained are tabulated in Table 5-5. It is evident that Holes 7,8,9&10 showed maximum deviation. This was because they were positioned directly under the inlet pipe and at lower heads the kinetic energy of the incoming jet caused the water to splash away from these orifices and so decreased the flow rate through them. The percentage deviation from the mean for individual heads developed over each orifice are tabulated in Table 5-6. In some cases, (Runs 6, 17 & 21) the effect of out-of-levelness of the distributor can be seen. This is manifested as a strong positive deviation on one side(Holes 1-4) and a strong negative deviation on the other side (Holes 14-18).

TABLE 5-5

PERCENTAGE DEVIATION FROM THE MEAN FLOW RATE

HOLE#

RUN#,(MEAN FLOW, GPM)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
INLET PIPE POSITION 1: 8.54 IN. FROM TROUGH BOTTOM.																		
4, (0.5763)	8.8	8.9	9.0	8.7	8.3	7.4	2.8	3.9	-184.1	-76.9	6.9	4.7	7.0	6.2	6.1	4.5	4.4	2.9
5, (0.8144)	5.8	5.3	5.2	5.3	5.4	4.5	-6.1	-6.4	2.0	-31.7	3.1	-4.1	4.0	3.8	4.2	3.0	3.6	3.4
6, (0.6973)	7.1	6.5	6.5	6.6	6.9	6.6	-2.4	-3.7	-32.1	-40.9	3.3	-3.9	3.2	3.0	2.4	3.2	2.1	2.0
7, (0.9266)	4.2	4.3	3.8	4.3	5.0	4.2	-3.3	-4.2	-18.0	-24.9	1.9	-2.2	3.3	3.0	2.8	2.6	1.8	1.8
8, (1.0412)	2.0	2.5	2.6	2.5	3.7	2.6	-2.9	-2.2	-10.4	-14.7	1.9	-0.4	2.3	2.1	1.9	1.3	0.3	1.3
9, (1.1473)	1.0	1.9	1.3	0.7	2.7	1.8	-1.9	-1.5	-5.0	-5.5	1.0	0.2	0.7	1.5	1.0	0.3	-0.8	-0.4
10, (1.2818)	0.4	0.2	-0.1	0.5	2.1	1.1	-0.5	-1.6	0.4	-1.0	1.1	-0.9	-0.1	0.3	0.5	-0.3	-1.1	-1.0
11, (1.3619)	5.0	3.3	3.8	3.3	3.4	2.3	-2.8	-5.4	-9.9	-12.2	1.5	-0.3	1.4	1.3	1.5	0.3	0.0	-0.1
12, (1.3616)	0.4	0.1	0.5	0.3	1.9	0.5	-0.6	-1.6	1.9	0.3	0.5	-0.3	-0.6	-0.3	-0.3	-0.1	-1.4	-1.1
13, (0.4206)	17.7	21.4	11.4	7.6	14.7	4.0	13.3	-30.1	-335.9	-548.1	13.1	-3.1	12.3	7.6	10.5	8.4	11.0	9.7
14, (0.3193)	27.8	32.9	17.7	7.0	23.5	-0.4	7.0	-148.9	-325.7	-402.8	-9.8	-114.3	18.6	6.6	21.5	14.1	20.0	20.6
INLET PIPE POSITION 2: 1.875 IN. FROM TROUGH BOTTOM.																		
15, (0.3366)	21.1	19.2	18.8	13.8	3.9	1.0	-109.3	-64.3	-79.6	-163.2	17.3	11.9	12.9	8.9	13.0	9.4	10.3	6.8
16, (0.4555)	11.4	10.1	9.3	8.7	9.1	8.2	5.4	2.5	-80.9	-57.5	3.4	3.5	1.2	-0.6	0.2	-2.8	3.3	1.4
17, (0.5705)	11.0	10.6	10.3	9.7	-80.9	9.1	-0.6	6.7	-39.0	-41.9	6.9	6.3	5.3	4.5	4.9	3.4	3.4	2.3
18, (0.6878)	4.1	4.9	4.7	3.8	4.1	2.1	-0.2	-4.4	-12.2	-13.8	1.0	0.3	1.6	0.9	1.2	-0.2	-0.3	-1.9
19, (0.8051)	5.0	3.3	3.8	3.3	3.4	2.3	-2.8	-5.4	-9.9	-12.2	1.5	-0.3	1.4	1.3	1.5	0.3	0.0	-0.1
20, (0.9195)	2.8	2.6	2.3	2.7	2.9	1.7	2.5	-5.1	-9.5	-11.4	1.5	0.6	0.7	1.0	1.3	1.1	-0.4	0.0
21, (1.0232)	2.0	1.9	2.8	3.0	3.3	1.8	-1.6	-3.4	-7.5	-8.5	2.1	1.5	1.0	1.5	0.5	-0.2	-1.3	-0.7
22, (1.1478)	0.3	0.5	1.5	1.1	2.4	0.9	-0.4	-2.4	-6.4	-7.8	2.5	1.9	1.0	1.2	1.3	0.7	-0.1	0.6
23, (1.2504)	0.4	0.8	0.6	1.2	2.5	1.3	0.1	-2.7	-4.7	-8.2	2.8	1.8	0.9	1.0	0.7	0.8	-0.3	0.1
24, (1.3431)	1.9	1.0	1.6	0.4	3.3	2.5	1.2	-1.3	28.9	-6.8	3.7	3.2	2.1	2.0	2.3	1.7	1.1	1.4

TABLE 5-6

PERCENTAGE DEVIATION FROM THE MEAN HEAD

RUN#,(MEAN HEAD, CM)	HOLE# 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
INLET PIPE POSITION 1: 8.54 IN. FROM TROUGH BOTTOM.																		
4, (2.84)	4.5	4.5	6.9	6.9	3.7	3.7	-11.4	-11.4	-8.0	-8.0	-5.2	-5.2	2.1	2.1	2.1	2.1	2.1	2.1
5, (6.15)	4.7	4.7	3.9	3.9	1.6	1.6	-0.8	-0.8	-1.7	-1.7	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
6, (4.24)	4.7	4.7	4.7	4.7	3.6	3.6	1.4	1.4	-1.0	-1.0	-3.4	-3.4	-6.0	-6.0	-3.4	-3.4	-3.4	-3.4
7, (8.06)	2.3	2.3	2.3	2.3	0.5	0.5	0.5	0.5	-0.1	-0.1	-0.8	-0.8	-3.3	-3.3	-0.8	-0.8	-2.0	-2.0
8, (10.50)	1.9	1.9	2.8	2.8	0.9	0.9	-0.5	-0.5	-1.0	-1.0	-1.5	-1.5	-1.0	-1.0	-1.0	-1.0	-1.9	-1.9
9, (13.04)	2.0	2.0	3.1	3.1	0.5	0.5	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-1.1	-1.1	-0.7	-0.7	-1.9	-1.9
10, (16.75)	1.5	1.5	2.1	2.1	0.3	0.3	1.2	1.2	0.2	0.2	-0.9	-0.9	-1.5	-1.5	-0.9	-0.9	-2.1	-2.1
11, (19.19)	1.1	1.1	1.8	1.8	0.1	0.1	0.6	0.6	-0.1	-0.1	-0.7	-0.7	-1.0	-1.0	-0.5	-0.5	-1.5	-1.5
12, (19.05)	1.3	1.3	1.8	1.8	0.3	0.3	0.0	0.0	-0.3	-0.3	-0.5	-0.5	-1.3	-1.3	-0.5	-0.5	-0.8	-0.8
13, (1.54)	14.4	14.4	14.4	14.4	3.8	3.8	-33.9	-33.9			-14.1	-14.1	-2.7	-2.7	3.8	3.8	-2.7	-2.7
14, (0.79)	21.0	21.0	16.8	16.8	-12.9	-12.9	-43.6	-43.6			-125.7	-125.7	12.2	12.2	21.0	21.0	12.2	12.2
INLET PIPE POSITION 2: 1.875 IN. FROM TROUGH BOTTOM.																		
15, (0.81)	26.4	26.4	37.7	37.7	-1.3	-1.3	-1520	-1520	-305.0	-305.0	19.0	19.0	22.9	22.9	14.7	14.7	4.7	4.7
16, (1.61)	19.5	19.5	10.6	10.6	17.4	17.4	-3.9	-3.9	-192.7	-192.7	5.3	5.3	10.6	10.6	-0.6	-0.6	-3.9	-3.9
17, (2.73)	11.9	11.9	9.0	9.0	7.5	7.5	-5.0	-5.0	-16.2	-16.2	-1.1	-1.1	2.5	2.5	-5.0	-5.0	-11.4	-11.4
18, (3.90)	0.0	0.0	3.9	3.9	2.5	2.5	1.3	1.3	-0.5	-0.5	-2.6	-2.6	0.0	0.0	-2.6	-2.6	-2.6	-2.6
19, (5.71)	1.6	1.6	2.4	2.4	3.2	3.2	0.7	0.7	-0.5	-0.5	-2.0	-2.0	-0.2	-0.2	-2.0	-2.0	-2.9	-2.9
20, (7.70)	2.5	2.5	1.9	1.9	2.5	2.5	1.9	1.9	0.4	0.4	-1.3	-1.3	0.0	0.0	-4.1	-4.1	-4.1	-4.1
21, (10.14)	2.5	2.5	3.0	3.0	1.6	1.6	2.0	2.0	0.9	0.9	-0.4	-0.4	-0.4	-0.4	-3.5	-3.5	-6.2	-6.2
22, (13.28)	-2.2	-2.2	-1.4	-1.4	-1.0	-1.0	2.4	2.4	1.3	1.3	0.2	0.2	0.2	0.2	0.5	0.5	0.2	0.2
23, (16.14)	-1.2	-1.2	-0.3	-0.3	-1.2	-1.2	1.6	1.6	0.9	0.9	0.1	0.1	0.1	0.1	0.4	0.4	-0.3	-0.3
24, (19.03)	-1.2	-1.2	-0.7	-0.7	-1.2	-1.2	1.4	1.4	0.8	0.8	0.1	0.1	-0.2	-0.2	1.1	1.1	-0.2	-0.2

Qualitative Description of Observed Maldistribution: Maldistribution effects were observed mostly at low inlet flow rates(10 gpm and lower). The holes located directly under the inlet pipe(Hole 9&10) exhibited the " tea-pot" effect for inlet flow rates below 8 gpm . This means that the flow rate through these holes was so low that the water slowly crept out along the sides of the trough and then discharged from the edge. For inlet flow rates between 8 and 14 gpm, the water jets discharging from these holes were not always continuous. They were often broken and wavy and spurted rather than flowed. At higher inlet flow rates, though the individual flows for these holes did not deviate quantitatively as much from the mean orifice flow, the water jets emerged laterally at an angle of approximately 25-30^{o} from the vertical. This could translate as over-irrigation of some part of the cross section of the column. For the holes adjacent to Nos. 9 and 10 i.e. Holes 7,8,11 and 12, the same effects were observed but to a much lesser extent. The angle of emergence of the jets however was 15-20^{o} and in the longitudinal direction, i.e. along the length of the trough. Besides the above mentioned effects some other phenomena were observed while conducting experiments. These included the formation of local shallow vortices on the water surface and some internal recirculation of water. The vortices were more like whirlpool formations occurring mainly at high inlet flow rates(above 18 gpm). Internal circulation of the water was observed sometimes at low flow rates (below 10 gpm). This occurred on one side of the trough i.e. for Holes 9-18. The holes in front would have jets inclined in one direction and the holes at the back would have jets inclined in the opposite direction. This however was not permanent and it typically occurred just after starting the experiment and persisted for about 20 minutes; then the flow would straighten out and stabilize.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The flow of a fluid through square-edged orifices in single orifice plates and in an actual distributor trough were studied. Flow rate and head data were collected. These data were then reduced to orifice coefficients and Reynolds numbers. The single orifice plate facility designed by Derasari(1991) was used to perform the tests on the orifice plates. For the trough tests, the recirculating loop designed and constructed by Chatorikar and Derasari(1991) was used. The distributor trough was supplied by Nutter Engineering, Tulsa, OK. It was a stainless steel trough, 11 gage(0.12 in.) thick, and had 18 orifices punched in it, each of 11/32 in. diameter. From the experiments the following conclusions were drawn.

Conclusions

1) From the single orifice plate studies, it was concluded that manufacturing tolerances and punch direction did not have any effect on the values of orifice coefficients. However, the presence of burrs was seen to have a slight influence on the flow through the orifice. Higher orifice coefficients were obtained for plates whose surfaces were deburred.
2) Given the inlet flow rate, a single value of the orifice coefficient could be obtained from single orifice plate tests which could then be used to predict the head in the distributor

trough. However, these predictions were accurate only for flow rates between 8 & 18 gpm. If predictions are to be made outside this range of inlet flow rates, then more than one value of the orifice coefficient will have to be obtained from the single orifice tests.

3) For heads more than 2 inches(5 cm.),which corresponded to Re > 5000, it was concluded that there is no significant interaction between holes. This means that for the same hole geometry, the same value of C_O was obtained for the single orifice tests and the multi-hole distributor tests.

4) Submerging the inlet pipe below the water surface did not seem to have any major effect on the distribution.

5) Flow distribution using the distributor trough was quantified in terms of the coefficient of variation for individual orifice flows. It was observed that for heads greater than 2 inches(5 cm.), the C_V values were less than 10%, which indicated reasonably good distribution. At lower heads, various degrees of maldistribution were observed. Hence, the distributor **should not be operated at heads less than 2 inches**.

6) The use of a momentum breaker improved the distribution but since it was located at the end of the trough rather than the center, more runs will have to be performed to validate this conclusion.

7) Leveling of the distributor was observed to be an important factor. The distribution deteriorated when the distributor was not leveled properly.

Recommendations

Experimental research in the field of liquid distributors provides valuable information necessary for the design of packed columns. The following suggestions are made for further research:

1) Conduct tests with and without the momentum breaker using the same inlet pipe position to compare qualities of distribution.
2) Conduct tests at heads less than 2 inches. These could provide useful information for turndown requirements.
3) Conduct tests using troughs having different hole sizes. Also, troughs with orifices punched in the sides could be tested.
4) Conduct more single orifice tests using different liquids to confirm whether the Reynolds number is indeed a sufficient correlating parameter.
5) The effect of the horizontal velocity component was studied in a parallel program in this project. Troughs having more than one orifice could be analyzed for the effect of the horizontal component of velocity.
6) Study the effects of out of levelness of the distributor using troughs inclined at some known angle to the horizontal. Sag and tilt effects can be thus analyzed.

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APPENDIX 1

PLATE NOMENCLATURE

In the nomenclature used to describe the orifice plates, the first letter represents the manufacturer code, the second number denotes the direction of flow relative to the punch direction, the third number denotes the plate thickness and hole diameter, and finally the last two letters indicate whether the plate is deburred or not. The different codes are described below.

Manufacturer Code: A - Koch; B - Nutter; C - Norton; D- Glitsch; E - ACS

ST - Standard Plates / Drilled Holes / O.S.U

Flow Direction Code: 0 - Parallel to Punch Direction; 1 - Counter to Punch Direction

Plate Thickness and Hole Diameter Code:

Plate Number	Plate Thickness	Hole Diameter, in.
1	0.25 in.	0.25
2	0.25 in.	0.50
3	0.25 in.	0.75
4	12 gage	0.25
5	12 gage	0.50
6	12 gage	0.75
7	14 gage	0.25
8	14 gage	0.50
9	14 gage	0.75

Deburring Code: ND - Non Deburred; DS / DB - Deburred Surface

Example: **A01ND** - A implies it is a Koch plate, 0 means the flow is parallel to the punch direction, 1 indicates that it is a 14 gage thick plate with a 0.25 in. hole and ND implies that it is not deburred.

APPENDIX 2

MEASUREMENTS OF ORIFICE PLATE HOLE DIAMETER

MANUFACTURER: B — **TABLE A2-1**

PLATE	PUNCH DIAMETER	MEASURED HOLE DIAMETER, INCHES										AVG HOLE DIA
		1	2	3	4	5	6	7	8	9	10	
B04ND	0.25	0.250	0.250	0.250	0.249	0.249	0.248	0.250	0.250	0.250	0.250	0.2496
B04DS	0.25	0.248	0.250	0.250	0.249	0.249	0.251	0.251	0.251	0.249	0.248	0.2496
B05ND	0.50	0.500	0.496	0.497	0.495	0.498	0.500	0.495	0.498	0.500	0.500	0.4979
B05DS	0.50	0.500	0.497	0.497	0.502	0.502	0.500	0.497	0.499	0.498	0.498	0.4990
B06DS	0.75	0.747	0.749	0.746	0.749	0.748	0.749	0.748	0.750	0.748	0.750	0.7484
B07ND	0.25	0.250	0.250	0.250	0.250	0.249	0.250	0.250	0.250	0.249	0.251	0.2499
B08ND	0.50	0.499	0.495	0.500	0.500	0.496	0.499	0.497	0.498	0.501	0.496	0.4981
B08DS	0.50	0.497	0.497	0.500	0.499	0.499	0.497	0.499	0.500	0.499	0.500	0.4987
B09ND	0.75	0.748	0.748	0.746	0.746	0.749	0.748	0.749	0.748	0.750	0.748	0.7480
B10ND	0.125	0.122	0.123	0.123	0.124	0.122	0.122	0.122	0.124	0.122	0.122	0.1226

APPENDIX 2(CONTD.)

MEASUREMENTS OF HOLE DIAMETER

MANUFACTURER: C

TABLE A2-2

PLATE	PUNCH DIAMETER	MEASURED HOLE DIAMETER, INCHES										AVG HOLE DIA
		1	2	3	4	5	6	7	8	9	10	
C05ND	0.50	0.499	0.497	0.498	0.498	0.498	0.499	0.498	0.500	0.500	0.495	0.4982
C08ND	0.50	0.493	0.500	0.493	0.497	0.495	0.500	0.496	0.500	0.497	0.499	0.4970

APPENDIX 2 (CONTD.)

MEASUREMENTS OF HOLE DIAMETER

MANUFACTURER: D

TABLE A2-3

PLATE	PUNCH DIAMETER	MEASURED HOLE DIAMETER , INCHES										AVG HOLE DIA
		1	2	3	4	5	6	7	8	9	10	
D01ND	0.25	0.252	0.255	0.255	0.255	0.256	0.257	0.255	0.250	0.250	0.250	0.2535
D02ND	0.50	0.499	0.497	0.498	0.500	0.499	0.496	0.500	0.499	0.499	0.496	0.4983
D03ND	0.75	0.748	0.748	0.750	0.750	0.750	0.748	0.746	0.751	0.750	0.749	0.7490
D05ND	0.50	0.499	0.494	0.495	0.497	0.498	0.497	0.497	0.499	0.499	0.496	0.4971
D08ND	0.50	0.500	0.499	0.501	0.500	0.496	0.495	0.500	0.500	0.501	0.500	0.4992

APPENDIX 2 (CONTD.)

MEASUREMENTS OF HOLE DIAMETER

MANUFACTURER: E

TABLE A2-4

PLATE	PUNCH DIAMETER	MEASURED HOLE DIAMETER, INCHES										AVG HOLE DIA
		1	2	3	4	5	6	7	8	9	10	
E05ND	0.50	0.501	0.501	0.498	0.501	0.498	0.501	0.499	0.499	0.501	0.500	0.4999
E08ND	0.50	0.501	0.501	0.500	0.502	0.502	0.500	0.497	0.501	0.500	0.502	0.5006

APPENDIX 3

MEASUREMENTS OF DISTRIBUTOR TROUGH HOLE DIAMETER, INCHES

TABLE A3-1

HOLE #	1	2	3	4	5	6	7	8	9	10	AVG. DIA.
1	0.347	0.345	0.344	0.344	0.346	0.342	0.344	0.348	0.345	0.342	0.3447
2	0.345	0.345	0.345	0.346	0.345	0.345	0.347	0.348	0.343	0.349	0.3458
3	0.345	0.345	0.345	0.346	0.347	0.346	0.345	0.347	0.345	0.346	0.3457
4	0.345	0.345	0.345	0.347	0.345	0.345	0.347	0.347	0.346	0.343	0.3455
5	0.347	0.347	0.347	0.346	0.346	0.345	0.343	0.347	0.346	0.348	0.3462
6	0.344	0.346	0.345	0.346	0.344	0.346	0.346	0.346	0.346	0.346	0.3455
7	0.347	0.348	0.344	0.346	0.347	0.341	0.347	0.340	0.347	0.347	0.3454
8	0.347	0.346	0.345	0.345	0.347	0.345	0.348	0.345	0.347	0.347	0.3462
9	0.346	0.346	0.346	0.345	0.344	0.342	0.346	0.342	0.346	0.345	0.3448
10	0.345	0.346	0.345	0.345	0.348	0.346	0.348	0.342	0.345	0.347	0.3457
11	0.348	0.347	0.345	0.345	0.346	0.348	0.344	0.347	0.346	0.348	0.3464
12	0.342	0.347	0.347	0.348	0.347	0.343	0.345	0.347	0.345	0.345	0.3456
13	0.346	0.348	0.347	0.347	0.345	0.347	0.348	0.346	0.347	0.346	0.3467
14	0.345	0.342	0.347	0.343	0.348	0.345	0.344	0.343	0.345	0.343	0.3445
15	0.343	0.348	0.345	0.346	0.345	0.342	0.347	0.343	0.346	0.347	0.3452
16	0.349	0.345	0.340	0.346	0.347	0.345	0.341	0.343	0.345	0.346	0.3447
17	0.346	0.344	0.344	0.344	0.343	0.345	0.348	0.349	0.346	0.346	0.3455
18	0.347	0.342	0.345	0.343	0.342	0.344	0.347	0.345	0.347	0.347	0.3449

APPENDIX 4

FLOW METER CALIBRATION
TABLE A4-1

FLOW RATE MEASURED GPM (A)	FLOWMETER READING GPM (B)	PERCENT ERROR 100*(A-B)/A
1.34	1.33	0.75
2.37	2.30	2.95
2.36	2.31	2.12
3.44	3.41	0.87
4.42	4.41	0.23
4.47	4.42	1.12
5.77	5.78	-0.17
5.72	5.77	-0.87
6.55	6.58	-0.46
6.45	6.61	-2.48
7.49	7.69	-2.67
7.57	7.68	-1.45
8.34	8.53	-2.28
8.50	8.48	0.24
9.33	9.41	-0.86
9.27	9.48	-2.27
10.56	10.70	-1.33
10.48	10.75	-2.58
11.44	11.60	-1.40
11.51	11.63	-1.04
12.47	12.58	-0.88
13.44	13.60	-1.19
13.37	13.57	-1.50
14.32	14.58	-1.82
14.51	14.60	-0.62
15.50	15.51	-0.06
15.25	15.51	-1.70
16.27	16.46	-1.17
16.16	16.52	-2.23
16.93	17.59	-3.90
17.33	17.60	-1.56
18.58	18.70	-0.65
18.41	18.70	-1.58
19.20	19.57	-1.93
19.47	19.58	-0.56
20.75	20.60	0.72
20.65	20.62	0.15
20.98	21.68	-3.34
21.78	21.75	0.14
22.99	22.57	1.83
22.63	22.60	0.13
23.94	23.55	1.63
	AVG. % ERROR	1.19

APPENDIX 5

Derivation of Orifice Coefficient Equation

Fig. A5-1 shows the stations to which the Bernoulli equation applies.

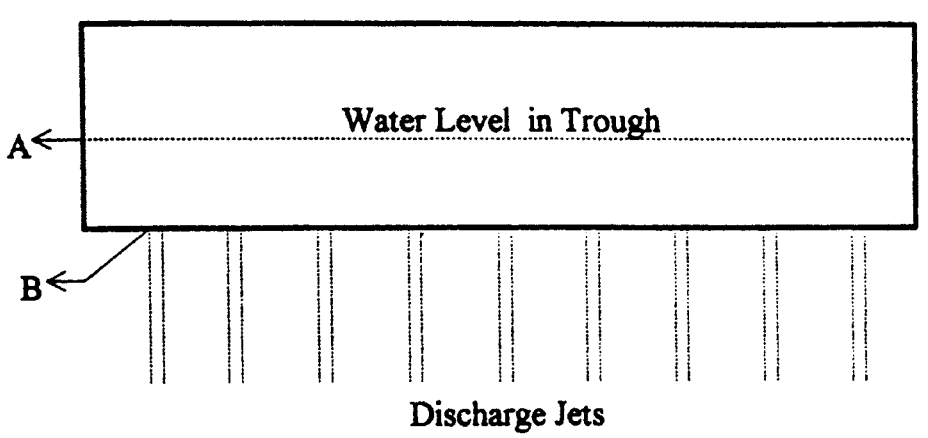

Fig. A5-1 Flow System Showing Stations For Use in Bernoulli's Equation
(Front View of Trough)

The main assumptions are:

1) Incompressible fluid

2) Steady state

3) Uniform flow across A and B

4) Pressures at A and B remain constant and are equal to the atmospheric pressure.

5) Frictional effects are negligible, i.e., they are not considered in the derivation but are incorporated through the orifice coefficient.

Bernoulli's Equation, using the above assumptions, can be written as

$$\frac{p_A}{\rho}+g\frac{Z_A}{g_c}+\frac{\alpha_A V_A^2}{2g_c}=\frac{P_B}{\rho}+\frac{gZ_B}{g_c}+\frac{\alpha V_B^2}{2g_c} \quad \text{.....(A5-1)}$$

This reduces to

$$\frac{\alpha_A V_A^2-\alpha_B V_B^2}{2g_c}=\frac{P_B-P_A}{\rho}+(Z_B-Z_A)\frac{g}{g_c} \quad \text{.....(A5-2)}$$

For an incompressible fluid , we can assume the density to be constant. The continuity equation then gives

$$-(Va/Vb)=\{(\pi D_B^2/4)(N)\}/A_T=\beta^2 \quad \text{.....(A5-3)}$$

where

$$D_A=2R_A=2\frac{A_T}{W_P} \quad \text{.....(A5-4)}$$

R_A = radius, m or ft

A_T = cross section area of the stream at the surface in the trough, m^2 or ft^2

W_P = wetted perimeter, m or ft

D_B = d = diameter of orifice

Substituting (A5-3) in (A5-2)

$$\frac{\alpha_A\beta^4 V_B^2-\alpha_B V_B^2}{2g_c}=\frac{P_B-P_A}{\rho}+(Z_B-Z_A)\frac{g}{g_c} \quad \text{.....(A5-5)}$$

$$V_B^2(\alpha_A\beta^4-\alpha_B)=\frac{P_B-P_A}{\rho}(2g_c)+(Z_B-Z_A)2g \quad \text{.....(A5-6)}$$

Since $P_A = P_B = P_{atmosphere}$ and Z_A-Z_B = h = liquid level above the orifice, eqn(A5-6) becomes

$$V_B^2(\alpha_A\beta^4-\alpha_B)=-2gh \quad \text{.....(A5-7)}$$

$$V_B^2=\frac{-2gh}{(\alpha_A\beta^4-\alpha_B)} \quad \text{.....(A5-8)}$$

The effects of jet contraction, kinetic energy correction and friction are incorporated in an orifice coefficient, C_o. Eqn(A5-8) becomes

$$V_B=\frac{C_o}{\sqrt{1-\beta^4}}\sqrt{2gh} \quad \text{.....(A5-9)}$$

This is the equation for determining the orifice coefficient.

For our case $\beta << 1$, so eqn (A5-9) becomes

$$V_B = C_o\sqrt{2gh} \quad \text{.....(A5-10)}$$

APPENDIX 6

SINGLE ORIFICE PLATE DATA

All the single orifice plate data taken are documented here. The measured variables were the head in cm., and the flow rate in ml/sec or gpm. The flow rate was initially measured using a cylinder and stopwatch. The data thus collected were in terms of ml/sec. These were then converted to gpm. Subsequently however, after calibration of the flow meter, the flow rate was measured directly in gpm using the same. The head and flow rate data were then converted to orifice coefficients and Reynolds numbers. Tables A6-1 to A6-7 show the data for tests on plates that were also tested by Derasari. All other data are collected using plates hitherto untested.

TABLE A6-1

Plate: A01ND
Hole Diameter: 0.2500 in.
Plate Thickness: 0.25 in.
Liquid: Water
Increasing Head
Non Deburred

Date:01/07/93
Liquid Temperature: 51.5 F
Liquid Density: 1000 Kg/Cu.m
Liquid Viscosity: 1.294 cp
Zero Point: 12.6 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.1	0.5	362.5	61.30	0.094	916	0.5961
14.1	1.5	417.5	27.50	0.241	2350	0.8829
19.2	6.6	462.5	15.60	0.469	4584	0.8210
21.5	8.9	435.0	13.20	0.522	5105	0.7873
23.3	10.7	412.5	11.80	0.555	5424	0.7630
29.9	17.3	425.0	10.10	0.668	6532	0.7225
35.6	23.0	442.5	9.67	0.725	7089	0.6801
36.8	24.2	477.5	10.20	0.746	7288	0.6816
38.9	26.3	420.0	8.57	0.777	7592	0.6811
59.5	46.9	472.5	7.35	1.019	9959	0.6691
59.9	47.3	377.5	6.06	0.988	9650	0.6456
60.5	47.9	397.5	6.16	1.023	9997	0.6645
61.3	48.7	420.0	6.41	1.039	10151	0.6692
65.3	52.7	405.0	6.02	1.067	10422	0.6605

TABLE A6-2

Plate: A01ND
Hole Diameter: 0.2500 in.
Plate Thickness: 0.25 in.
Liquid: Water
Decreasing Head
Non Deburred

Date:01/07/93
Liquid Temperature: 51.5 F
Liquid Density: 1000 KG/CU.M
Liquid Viscosity: 1.294 cp
Zero Point: 12.6 CM
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
63.7	51.10	405.0	5.97	1.075	10509	0.6764
62.5	49.90	370.0	5.52	1.063	10384	0.6763
55.0	42.40	395.0	6.34	0.988	9652	0.6820
53.0	40.40	380.0	6.59	0.914	8933	0.6466
47.0	34.40	372.5	6.97	0.847	8279	0.6495
44.5	31.90	435.0	8.32	0.829	8100	0.6598
43.5	30.90	430.0	8.41	0.811	7921	0.6556
38.0	25.40	277.5	5.81	0.757	7399	0.6755
32.5	19.90	225.0	5.44	0.656	6407	0.6608
25.2	12.60	465.0	12.84	0.574	5610	0.7272
20.5	7.90	402.5	12.86	0.496	4848	0.7937
17.6	5.00	405.0	15.76	0.407	3981	0.8191
14.4	1.80	407.5	29.88	0.216	2112	0.7245
13.6	1.00	410.0	34.27	0.190	1853	0.8527
13.2	0.55	320.0	39.70	0.128	1248	0.7747

TABLE A6-3

Plate: ST01ND
Hole Diameter: 0.2495 in.
Plate Thickness: 0.25 in.
Liquid: Water
Increasing Head
Drilled Hole

Date:01/17/93
Liquid Temperature: 47.5 F
Liquid Density: 999.8 Kg/Cu.m
Liquid Viscosity: 1.378 cp
Zero Point: 12.3 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF
13.10	0.80	435	101.00	0.068	627	0.3446
16.00	3.70	435	18.68	0.369	3393	0.8663
18.60	6.30	420	13.54	0.492	4520	0.8844
20.10	7.80	400	11.30	0.561	5159	0.9070
20.80	8.50	460	12.67	0.576	5291	0.8911
22.55	10.25	450	11.05	0.646	5935	0.9103
24.45	12.15	467.5	10.69	0.693	6373	0.8978
25.65	13.35	487.5	10.51	0.735	6760	0.9085
29.90	17.60	430	8.12	0.840	7717	0.9033
31.10	18.80	470	8.66	0.860	7909	0.8957
32.80	20.50	455	8.24	0.875	8047	0.8727
37.30	25.00	465	7.52	0.980	9012	0.8850
54.90	42.60	452.5	7.07	1.015	9327	0.7017

TABLE A6-4

Plate: ST01ND
Hole Diameter: 0.2495 in.
Plate Thickness: 0.25 in.
Liquid: Water
Decreasing Head
Drilled Hole

Date:01/17/93
Liquid Temperature: 47.5 F
Liquid Density: 999.8 Kg/Cu.m
Liquid Viscosity: 1.378 cp
Zero Point: 12.3 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF
54.90	42.60	425.5	7.07	0.9540	8771	0.6599
53.70	41.40	435.0	6.90	0.9994	9188	0.7012
52.90	40.60	470.0	7.23	1.0305	9474	0.7301
51.20	38.90	437.5	6.97	0.9950	9148	0.7202
46.45	34.15	452.5	7.63	0.9401	8643	0.7262
40.00	27.70	435.0	8.22	0.8389	7712	0.7195
31.60	19.30	460.0	10.13	0.7198	6618	0.7397
27.80	15.50	420.0	10.27	0.6483	5960	0.7433
24.50	12.20	435.0	11.81	0.5839	5368	0.7546
23.10	10.80	440.0	12.17	0.5731	5269	0.7673
21.65	9.35	410.0	12.24	0.5310	4881	0.7839
18.40	6.10	437.5	13.93	0.4979	4577	0.9100
17.35	5.05	425.0	15.38	0.4380	4027	0.8800
17.00	4.70	452.5	17.54	0.4090	3759	0.8516
16.45	4.15	475.0	19.51	0.3859	3548	0.8552
15.65	3.35	470.0	21.87	0.3407	3132	0.8402
14.80	2.50	450.0	24.74	0.2883	2650	0.8232
14.20	1.90	475.0	31.69	0.2376	2184	0.7782

TABLE A6-5

Plate: B14DS
Hole Diameter: 0.2490 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Deburred

Date:01/11/93
Liquid Temperature: 51 F
Liquid Density: 1000 Kg/Cu.m
Liquid Viscosity: 1.304 cp
Zero Point: 11.7 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.70	2.00	412.5	31.27	0.2091	2036	0.6702
14.85	3.15	462.5	27.74	0.2643	2573	0.6749
15.15	3.45	457.5	26.24	0.2764	2691	0.6744
15.70	4.00	412.5	21.33	0.3066	2985	0.6947
16.00	4.30	415.0	20.84	0.3157	3073	0.6900
16.75	5.05	460.0	21.15	0.3448	3357	0.6954
18.90	7.20	472.5	17.36	0.4315	4201	0.7288
20.90	9.20	415.0	13.32	0.4939	4809	0.7380
23.90	12.20	405.0	11.54	0.5563	5417	0.7219
26.25	14.55	445.0	11.93	0.5913	5757	0.7026
31.50	19.80	455.0	10.83	0.6660	6484	0.6784
32.75	21.05	415.0	9.37	0.7021	6836	0.6936
36.00	24.30	475.0	10.24	0.7363	7169	0.6761
38.75	27.05	432.5	8.74	0.7844	7638	0.6836
44.80	33.10	470.0	8.78	0.8486	8262	0.6685
54.30	42.60	425.0	7.15	0.9423	9174	0.6543

TABLE A6-6

Plate: B14DS
Hole Diameter: 0.2490 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Deburred

Date:01/11/93
Liquid Temperature: 51 F
Liquid Density: 1000 Kg/Cu.m
Liquid Viscosity: 1.304 cp
Zero Point: 11.7 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
54.30	42.60	425	7.15	0.9423	9174	0.6543
52.60	40.90	435	7.48	0.9219	8976	0.6533
45.90	34.20	435	8.10	0.8513	8289	0.6598
44.30	32.60	450	8.53	0.8363	8142	0.6639
38.15	26.45	410	8.31	0.7821	7615	0.6893
32.50	20.80	425	9.59	0.7025	6840	0.6982
28.50	16.80	425	10.72	0.6285	6119	0.6950
26.50	14.80	440	11.88	0.5871	5716	0.6917
25.15	13.45	435	12.21	0.5648	5499	0.6980
24.30	12.60	440	12.81	0.5445	5301	0.6952
19.95	8.25	445	15.52	0.4545	4425	0.7172
18.75	7.05	435	16.81	0.4102	3994	0.7002
15.05	3.35	425	24.71	0.2726	2654	0.6752

TABLE A6-7

Plate: A05ND
Hole Diameter: 0.4985 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Non Deburred

Date:02/27/93
Liquid Temperature: 50 F
Liquid Density: 999.699 Kg/Cu.m
Liquid Viscosity: 1.325 cp
Zero Point: 12.95 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.75	0.80	935	17.72	0.8364	4002	1.0575
14.05	1.10	915	15.82	0.9169	4387	0.9886
14.50	1.55	920	14.70	0.9921	4747	0.9011
14.90	1.95	935	13.69	1.0827	5180	0.8768
15.15	2.20	950	13.09	1.1505	5505	0.8771
15.50	2.55	935	12.01	1.2341	5905	0.8739
15.95	3.00	1550	18.77	1.3090	6263	0.8547
16.25	3.30	1600	18.42	1.3769	6588	0.8572
16.65	3.70	1630	18.14	1.4244	6816	0.8374
17.10	4.15	1740	18.44	1.4958	7157	0.8303
17.70	4.75	1820	18.26	1.5800	7560	0.8198
18.40	5.45	1700	16.09	1.6749	8014	0.8113
19.15	6.20	1880	16.88	1.7655	8448	0.8018
19.80	6.85	1820	15.65	1.8435	8821	0.7965
20.65	7.70	1900	15.52	1.9406	9286	0.7909
21.30	8.35	1810	14.27	2.0107	9621	0.7869
22.65	9.70	1860	13.74	2.1459	10268	0.7792
23.15	10.20	1900	13.60	2.2146	10597	0.7842
24.40	11.45	1920	13.50	2.2545	10788	0.7534
24.85	11.90	1820	12.44	2.3192	11097	0.7603
25.60	12.65	1900	12.72	2.3678	11330	0.7528
26.30	13.35	1880	12.33	2.4170	11565	0.7481
27.00	14.05	1840	11.77	2.4781	11858	0.7476
27.75	14.80	1900	11.82	2.5481	12193	0.7490
28.45	15.50	1820	11.25	2.5645	12271	0.7366
29.15	16.20	1840	11.06	2.6372	12619	0.7410
29.90	16.95	1850	10.98	2.6709	12780	0.7336

TABLE A6-7(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
30.60	17.65	1830	10.53	2.7549	13182	0.7415
31.30	18.35	1880	10.59	2.8141	13466	0.7429
32.10	19.15	1880	10.39	2.8683	13725	0.7412
32.85	19.90	1840	9.99	2.9197	13971	0.7401
33.50	20.55	1930	10.41	2.9389	14063	0.7331
34.00	21.05	1960	10.40	2.9875	14295	0.7363
34.85	21.90	1890	9.88	3.0324	14510	0.7328
35.95	23.00	1880	9.59	3.1076	14870	0.7328
36.35	23.40	1830	9.34	3.1059	14862	0.7261
37.50	24.55	1840	9.20	3.1704	15170	0.7236
38.45	25.50	1900	9.14	3.2953	15768	0.7379
39.05	26.10	1900	9.06	3.3244	15907	0.7359

TABLE A6-8

Plate: A05ND
Hole Diameter: 0.4985 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Non Deburred

Date:02/27/93
Liquid Temperature: 50 F
Liquid Density: 999.699 Kg/Cu.m
Liquid Viscosity: 1.325 cp
Zero Point: 12.95 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
39.05	26.10	1900.0	9.06	3.3244	15907	0.7359
38.70	25.75	1820.0	8.73	3.3048	15813	0.7365
38.00	25.05	2000.0	9.99	3.1736	15186	0.7170
37.30	24.35	1880.0	9.41	3.1670	15154	0.7258
36.50	23.55	1810.0	9.36	3.0654	14668	0.7143
35.85	22.90	1810.0	9.20	3.1187	14923	0.7370
35.00	22.05	1810.0	9.45	3.0362	14528	0.7312
34.20	21.25	1870.0	9.84	3.0125	14415	0.7390
33.45	20.50	1870.0	10.06	2.9466	14100	0.7360
32.65	19.70	1840.0	10.10	2.8879	13819	0.7358
31.90	18.95	1850.0	10.37	2.8280	13532	0.7346
31.10	18.15	1990.0	11.31	2.7892	13346	0.7404
30.25	17.30	1850.0	10.85	2.7029	12933	0.7349
29.45	16.50	1900.0	11.38	2.6466	12664	0.7368
28.70	15.75	1900.0	11.49	2.6213	12543	0.7469
28.00	15.05	1950.0	12.16	2.5421	12164	0.7410
27.15	14.20	1960.0	12.37	2.5117	12019	0.7538
26.40	13.45	1970.0	12.74	2.4512	11729	0.7568
25.80	12.85	1850.0	12.30	2.3842	11409	0.7521
25.05	12.10	1920.0	13.08	2.3269	11134	0.7565
24.40	11.45	1910.0	13.18	2.2972	10992	0.7677
23.40	10.45	1930.0	14.02	2.1822	10442	0.7634
22.70	9.75	1880.0	13.74	2.1690	10378	0.7855
21.50	8.55	1900.0	15.00	2.0079	9608	0.7765
20.75	7.80	1900.0	15.34	1.9634	9395	0.7950
20.10	7.15	1890.0	15.97	1.8760	8977	0.7934
19.55	6.60	1880.0	16.49	1.8073	8648	0.7955

TABLE A6-8(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18.80	5.85	1890.0	17.49	1.7130	8196	0.8009
18.30	5.35	1910.0	18.40	1.6455	7874	0.8045
17.90	4.95	1960.0	19.49	1.5941	7628	0.8103
17.30	4.35	1930.0	19.99	1.5305	7323	0.8298
16.80	3.85	1910.0	20.90	1.4487	6932	0.8349
16.00	3.05	1920.0	22.81	1.3343	6384	0.8640
15.25	2.30	1920.0	25.16	1.2097	5788	0.9020
14.70	1.75	1910.0	28.13	1.0763	5150	0.9201
13.80	0.85	1390.0	25.71	0.8570	4101	1.0512

TABLE A6-9

Plate: A18ND
Hole Diameter: 0.5004 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Non Deburred

Date:02/28/93
Liquid Temperature: 50 F
Liquid Density: 999.699 Kg/Cu.m
Liquid Viscosity: 1.325 cp
Zero Point: 12.75 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.15	0.40	915	23.55	0.6159	2936	1.0929
13.30	0.55	905	21.43	0.6694	3191	1.0130
13.55	0.80	905	19.52	0.7349	3503	0.9222
13.80	1.05	920	17.66	0.8258	3936	0.9044
14.15	1.40	910	15.88	0.9084	4330	0.8616
14.45	1.70	1470	23.69	0.9836	4689	0.8467
15.15	2.40	1710	23.62	1.1476	5470	0.8314
15.40	2.65	1790	23.90	1.1872	5659	0.8185
15.70	2.95	1650	20.95	1.2485	5951	0.8158
15.95	3.20	1870	22.66	1.3082	6236	0.8207
15.95	3.20	1940	23.66	1.2998	6196	0.8154
16.20	3.45	1810	21.40	1.3408	6391	0.8101
16.20	3.45	1940	22.61	1.3601	6483	0.8218
16.55	3.80	1830	20.74	1.3987	6667	0.8053
16.55	3.80	1995	22.42	1.4106	6724	0.8121
16.95	4.20	1860	20.11	1.4662	6989	0.8029
16.95	4.20	2085	22.59	1.4631	6974	0.8012
17.35	4.60	1795	18.60	1.5298	7292	0.8005
17.35	4.60	1830	18.99	1.5276	7282	0.7993
17.70	4.95	1890	19.06	1.5719	7493	0.7929
17.70	4.95	1[illegible]	16.00	1.5852	7556	0.7996
18.10	5.35	1855	17.96	1.6373	7804	0.7944
18.10	5.35	1830	17.72	1.6371	7804	0.7943
18.70	5.95	1790	16.64	1.7052	8128	0.7846
18.70	5.95	1825	16.89	1.7128	8165	0.7881
19.15	6.40	1815	16.27	1.7684	8429	0.7845
19.20	6.45	1920	16.95	1.7956	8559	0.7935

TABLE A6-9(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
19.75	7.00	1820	15.52	1.8470	8804	0.7835
19.70	6.95	1865	15.98	1.8501	8819	0.7876
20.40	7.65	1775	14.73	1.9102	9105	0.7751
20.40	7.65	1935	15.98	1.9195	9150	0.7789
20.95	8.20	1835	14.76	1.9708	9394	0.7724
21.00	8.25	1870	15.02	1.9736	9408	0.7711
21.40	8.65	1775	13.93	2.0199	9628	0.7708
21.40	8.65	1890	14.74	2.0326	9689	0.7756
22.95	10.20	1930	14.05	2.1775	10380	0.7652
22.95	10.20	1835	13.27	2.1920	10449	0.7703
23.50	10.75	1825	12.92	2.2392	10674	0.7664
23.60	10.85	1875	13.24	2.2449	10701	0.7649
24.15	11.40	1890	13.03	2.2993	10960	0.7643
24.20	11.45	1860	12.83	2.2981	10955	0.7622
24.80	12.05	1810	12.30	2.3327	11119	0.7542
24.85	12.10	1890	12.83	2.3352	11131	0.7534
25.55	12.80	1795	11.90	2.3911	11398	0.7501
25.50	12.75	1820	12.08	2.3883	11385	0.7506
25.90	13.15	1820	11.97	2.4102	11489	0.7459
26.00	13.25	1845	11.95	2.4474	11667	0.7546
27.10	14.35	1750	10.99	2.5242	12032	0.7478
27.30	14.55	1900	11.83	2.5460	12136	0.7491
27.90	15.15	1940	11.89	2.5884	12329	0.7458
27.95	15.20	1860	11.50	2.5639	12222	0.7380
28.75	16.00	1835	11.04	2.6348	12560	0.7392
28.80	16.05	1920	11.52	2.6420	12594	0.7401
29.35	16.60	1950	11.50	2.6879	12813	0.7404
29.45	16.70	1855	10.87	2.7052	12895	0.7429
30.25	17.50	1855	10.74	2.7379	13051	0.7345
30.30	17.55	1775	10.31	2.7291	13009	0.7311
31.10	18.35	1850	10.66	2.7511	13114	0.7207
31.20	18.45	1835	10.44	2.7862	13282	0.7280
31.80	19.05	1780	10.06	2.8048	13370	0.7212
31.80	19.05	1840	10.34	2.8209	13447	0.7253

TABLE A6-9(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
32.80	20.05	1800	9.91	2.8793	13725	0.7216
32.80	20.05	1835	9.99	2.9118	13880	0.7298
33.55	20.80	1740	9.38	2.9406	14017	0.7236
33.60	20.85	1790	9.59	2.9588	14104	0.7272
34.30	21.55	1775	9.34	3.0126	14360	0.7283
34.75	22.00	1840	9.70	3.0070	14334	0.7195
35.95	23.20	1800	9.37	3.0452	14516	0.7095
35.95	23.20	1820	9.22	3.1291	14916	0.7291
36.40	23.65	1780	9.14	3.0872	14716	0.7124
37.15	24.40	1850	9.19	3.1911	15212	0.7250
37.85	25.10	1900	9.38	3.2110	15306	0.7193
38.50	25.75	1680	8.23	3.2359	15425	0.7157
39.30	26.55	1835	8.85	3.2868	15668	0.7159
39.45	26.70	1820	8.54	3.3783	16104	0.7337

TABLE A6-10

Plate: A18ND
Hole Diameter: 0.5004 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Non Deburred

Date:02/28/93
Liquid Temperature: 50 F
Liquid Density: 999.699 Kg/Cu.m
Liquid Viscosity: 1.325 cp
Zero Point: 12.75 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
39.45	26.70	1820	8.54	3.3783	16104	0.7337
38.85	26.10	1755	8.47	3.2846	15657	0.7215
38.85	26.10	1890	9.01	3.3252	15851	0.7305
38.00	25.25	1830	9.06	3.2019	15263	0.7151
37.65	24.90	1660	8.16	3.2248	15372	0.7253
36.60	23.85	1855	9.40	3.1282	14912	0.7189
36.55	23.80	1850	9.35	3.1365	14951	0.7215
35.30	22.55	1660	8.61	3.0563	14569	0.7223
35.30	22.55	1850	9.54	3.0740	14653	0.7265
34.70	21.95	1930	9.93	3.0810	14687	0.7380
34.50	21.75	1800	9.45	3.0194	14393	0.7266
33.45	20.70	1760	9.28	3.0064	14331	0.7416
33.45	20.70	1900	10.12	2.9762	14187	0.7341
32.60	19.85	1830	10.01	2.8980	13814	0.7300
32.55	19.80	1900	10.35	2.9100	13872	0.7339
31.55	18.80	1735	9.66	2.8471	13572	0.7369
31.50	18.75	1730	9.69	2.8301	13491	0.7335
30.70	17.95	1755	10.21	2.7248	12989	0.7218
30.65	17.90	1735	9.92	2.7725	13216	0.7364
29.60	16.85	1750	10.29	2.6959	12851	0.7371
29.55	16.80	1760	10.30	2.7087	12912	0.7417
28.40	15.65	1890	11.45	2.6166	12473	0.7423
28.40	15.65	1840	11.06	2.6372	12571	0.7481
27.55	14.80	1840	11.38	2.5631	12218	0.7477
27.50	14.75	1960	12.20	2.5467	12140	0.7442
26.45	13.70	1730	11.04	2.4841	11841	0.7532
26.45	13.70	1870	11.91	2.4889	11864	0.7547

TABLE A6-10(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
25.50	12.75	1820	12.02	2.4002	11441	0.7544
25.50	12.75	1760	11.69	2.3866	11377	0.7501
24.70	11.95	1780	12.12	2.3281	11098	0.7558
24.65	11.90	1800	12.22	2.3350	11130	0.7596
23.65	10.90	1700	12.00	2.2457	10705	0.7634
23.60	10.85	1770	12.57	2.2321	10640	0.7605
22.80	10.05	1840	13.40	2.1767	10376	0.7706
22.80	10.05	1780	12.99	2.1722	10354	0.7690
21.45	8.70	1795	13.98	2.0354	9702	0.7744
21.40	8.65	1870	14.45	2.0514	9779	0.7828
20.35	7.60	1800	14.73	1.9371	9234	0.7886
20.35	7.60	1840	15.21	1.9177	9141	0.7807
19.65	6.90	1880	16.34	1.8239	8694	0.7792
19.65	6.90	1870	15.22	1.9477	9284	0.8321
18.80	6.05	1770	16.42	1.7088	8145	0.7797
18.70	5.95	1700	15.66	1.7208	8203	0.7917
17.75	5.00	1730	17.39	1.5770	7517	0.7915
17.80	5.05	1770	17.73	1.5825	7543	0.7903
16.90	4.15	1780	19.34	1.4590	6954	0.8037
16.85	4.10	1750	19.06	1.4555	6938	0.8067
16.00	3.25	1530	18.27	1.3275	6328	0.8264
16.05	3.30	1845	21.92	1.3343	6360	0.8243
15.60	2.85	1830	23.15	1.2531	5973	0.8330
15.60	2.85	1835	23.18	1.2549	5982	0.8342
14.55	1.80	1560	23.95	1.0325	4922	0.8637
14.60	1.85	1570	23.98	1.0378	4947	0.8563
13.40	0.65	1550	36.99	0.6642	3166	0.9246
13.30	0.55	1300	31.40	0.6563	3128	0.9931

TABLE A6-11

Plate: A07ND
Hole Diameter: 0.2496 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Non Deburred

Date:03/02/93
Liquid Temperature: 52 F
Liquid Density: 999.599 Kg/Cu.m
Liquid Viscosity: 1.289 cp
Zero Point: 12.7 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.60	0.90	410	34.03	0.1910	1875	0.9081
13.60	0.90	478	39.38	0.1924	1889	0.9149
14.25	1.55	500	32.38	0.2448	2403	0.8869
14.35	1.65	580	37.03	0.2483	2438	0.8719
15.30	2.60	642	34.20	0.2976	2922	0.8324
15.55	2.85	715	36.56	0.3100	3044	0.8283
15.70	3.00	635	31.74	0.3171	3114	0.8259
16.75	4.05	720	31.40	0.3635	3569	0.8147
16.90	4.20	735	31.52	0.3696	3630	0.8136
18.45	5.75	838	31.27	0.4248	4171	0.7991
18.50	5.80	845	31.31	0.4278	4201	0.8013
19.90	7.20	905	30.57	0.4693	4608	0.7889
20.05	7.35	915	30.52	0.4752	4667	0.7907
21.45	8.75	925	28.60	0.5127	5034	0.7818
21.50	8.80	932	28.56	0.5173	5080	0.7866
22.60	9.90	870	25.13	0.5488	5389	0.7867
22.85	10.15	939	26.92	0.5529	5430	0.7829
23.60	10.90	890	24.75	0.5700	5597	0.7788
23.60	10.90	935	25.74	0.5758	5654	0.7867
24.95	12.25	913	23.98	0.6035	5927	0.7778
25.05	12.35	928	24.17	0.6086	5977	0.7812
26.40	13.70	930	23.31	0.6324	6210	0.7707
26.50	13.80	955	23.70	0.6388	6272	0.7756
29.05	16.35	855	19.59	0.6919	6794	0.7718
29.30	16.60	900	20.59	0.6929	6804	0.7671
30.30	17.60	887	19.83	0.7091	6963	0.7624
30.40	17.70	988	22.02	0.7113	6984	0.7626

TABLE A6-11(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
31.90	19.20	770	16.45	0.7420	7286	0.7638
32.60	19.90	1595	33.31	0.7590	7454	0.7675
32.70	20.00	1550	32.05	0.7666	7528	0.7732
33.00	20.30	1575	32.31	0.7727	7588	0.7736
33.00	20.30	1510	30.92	0.7741	7602	0.7750
34.00	21.30	1580	31.86	0.7861	7720	0.7683
34.15	21.45	1630	32.52	0.7945	7802	0.7738
36.30	23.60	1920	36.61	0.8314	8164	0.7719
36.50	23.80	1730	33.10	0.8285	8136	0.7660
40.00	27.30	1760	31.58	0.8835	8675	0.7627
40.75	28.05	1750	31.02	0.8943	8782	0.7617
41.00	28.30	1800	31.76	0.8984	8822	0.7618
41.65	28.95	1740	30.59	0.9017	8854	0.7559
42.00	29.30	1720	29.79	0.9153	8988	0.7627
42.75	30.05	1800	31.02	0.9198	9033	0.7569
43.20	30.50	1600	27.60	0.9190	9024	0.7506
44.35	31.65	1830	31.00	0.9358	9189	0.7503
46.00	33.30	1870	30.56	0.9700	9525	0.7582
46.30	33.60	1690	27.36	0.9792	9615	0.7620
46.75	34.05	1830	29.47	0.9844	9666	0.7609
48.35	35.65	1920	30.49	0.9982	9802	0.7541
49.05	36.35	2000	31.41	1.0094	9912	0.7552
49.50	36.80	1950	30.47	1.0145	9962	0.7543
49.50	36.80	1665	26.10	1.0112	9930	0.7519

TABLE A6-12

Plate: A07ND
Hole Diameter: 0.2496 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Non Deburred

Date:03/02/93
Liquid Temperature: 52 F
Liquid Density: 999.599 Kg/Cu.m
Liquid Viscosity: 1.289 cp
Zero Point: 12.7 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
49.50	36.80	1665	26.10	1.0112	9930	0.7519
48.40	35.70	1915	30.49	0.9956	9777	0.7516
48.15	35.45	1935	30.63	1.0014	9834	0.7587
47.65	34.95	1930	30.85	0.9917	9739	0.7567
47.40	34.70	1890	30.48	0.9829	9652	0.7527
46.05	33.35	1895	30.88	0.9728	9553	0.7598
46.00	33.30	1915	31.45	0.9652	9478	0.7545
44.50	31.80	1820	30.31	0.9519	9347	0.7614
44.20	31.50	1840	31.02	0.9403	9234	0.7557
44.10	31.40	1820	30.49	0.9462	9292	0.7617
43.45	30.75	1810	30.57	0.9386	9217	0.7635
43.40	30.70	1795	30.72	0.9262	9096	0.7541
42.70	30.00	1890	30.95	0.9680	9506	0.7972
42.40	29.70	1770	30.59	0.9172	9007	0.7592
42.05	29.35	1800	31.49	0.9061	8898	0.7544
41.25	28.55	1760	30.83	0.9049	8886	0.7639
40.95	28.25	1720	30.68	0.8887	8727	0.7542
40.00	27.30	1695	30.72	0.8746	8589	0.7551
39.15	26.45	1680	30.56	0.8714	8557	0.7643
38.50	25.80	1650	30.45	0.8590	8435	0.7628
38.30	25.60	1720	32.09	0.8497	8343	0.7575
37.50	24.80	1670	31.25	0.8471	8319	0.7673
37.10	24.40	1645	31.09	0.8387	8236	0.7659
36.25	23.55	1650	31.76	0.8235	8087	0.7655
35.85	23.15	1590	30.62	0.8231	8083	0.7717
34.35	21.65	1570	31.14	0.7992	7848	0.7748
33.15	20.45	1540	31.46	0.7760	7620	0.7740

TABLE A6-12(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
32.55	19.85	1645	34.44	0.7572	7435	0.7666
32.35	19.65	1910	40.02	0.7566	7429	0.7698
31.15	18.45	1420	30.63	0.7349	7216	0.7717
30.05	17.35	1410	31.34	0.7132	7003	0.7723
29.75	17.05	1690	37.97	0.7056	6928	0.7707
29.60	16.90	1450	32.58	0.7055	6928	0.7741
28.45	15.75	1810	42.22	0.6796	6673	0.7724
27.85	15.15	1320	31.41	0.6662	6542	0.7720
27.00	14.30	1370	33.33	0.6516	6398	0.7772
26.80	14.10	1410	34.61	0.6458	6342	0.7758
25.50	12.80	1300	33.41	0.6168	6057	0.7777
25.00	12.30	1190	30.70	0.6145	6034	0.7903
24.25	11.55	1310	34.92	0.5947	5839	0.7893
23.70	11.00	1110	30.70	0.5732	5628	0.7795
23.40	10.70	1150	31.77	0.5738	5635	0.7913
22.65	9.95	1130	32.54	0.5505	5406	0.7872
21.00	8.30	1030	31.83	0.5130	5037	0.8031
20.55	7.85	1600	33.71	0.7524	7388	1.2113
20.45	7.75	910	29.89	0.4826	4739	0.7820
19.50	6.80	870	30.62	0.4504	4423	0.7791
18.95	6.25	895	32.06	0.4425	4345	0.7984
18.20	5.50	845	32.38	0.4137	4062	0.7957
18.10	5.40	798	30.91	0.4092	4018	0.7944
16.30	3.60	795	36.82	0.3423	3361	0.8137
16.00	3.30	650	30.98	0.3326	3266	0.8259
14.80	2.10	530	31.20	0.2693	2644	0.8382
14.30	1.60	480	30.66	0.2482	2437	0.8850
13.40	0.70	610	50.08	0.1931	1896	1.0410

TABLE A6-13

Plate: B08ND
Hole Diameter: 0.4981 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Non Deburred

Date:03/23/93
Liquid Temperature: 56 F
Liquid Density: 999.338 Kg/Cu.m
Liquid Viscosity: 1.207 cp
Zero Point: 12.25 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
12.85	0.60	515	18.22	0.4481	2344	0.6552
12.85	0.60	1210	36.35	0.5277	2760	0.7716
13.05	0.80	1300	31.30	0.6584	3444	0.8338
13.05	0.80	1330	32.26	0.6535	3419	0.8276
13.55	1.30	1685	31.38	0.8512	4453	0.8456
13.55	1.30	1700	31.67	0.8509	4451	0.8453
13.85	1.60	1860	31.79	0.9275	4852	0.8305
13.85	1.60	1840	31.70	0.9201	4813	0.8239
14.85	2.60	1790	24.41	1.1624	6081	0.8165
14.85	2.60	1830	26.41	1.0984	5746	0.7716
15.35	3.10	1860	23.60	1.2494	6536	0.8037
15.40	3.15	2060	26.13	1.2497	6538	0.7975
15.90	3.65	1850	21.98	1.3342	6980	0.7910
15.90	3.65	1965	23.11	1.3479	7051	0.7991
16.85	4.60	1980	21.27	1.4756	7720	0.7793
16.90	4.65	1920	20.51	1.4840	7763	0.7795
17.25	5.00	1995	20.69	1.5285	7996	0.7742
17.30	5.05	1995	20.45	1.5464	8090	0.7794
17.50	5.25	1905	19.31	1.5639	8181	0.7731
17.55	5.30	1860	18.79	1.5692	8209	0.7720
17.90	5.65	1855	18.34	1.6034	8388	0.7640
17.90	5.65	1920	18.69	1.6285	8519	0.7760
18.35	6.10	1885	17.99	1.6610	8689	0.7617
18.35	6.10	2000	18.89	1.6783	8780	0.7697
18.75	6.50	1910	17.64	1.7164	8979	0.7625
18.80	6.55	1920	17.79	1.7108	8950	0.7572
19.45	7.20	1810	16.77	1.8194	9518	0.7680

TABLE A6-13(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
19.55	7.30	1940	17.16	1.7921	9376	0.7513
20.50	8.25	2005	16.68	1.9055	9969	0.7514
20.50	8.25	1900	15.58	1.9332	10114	0.7623
21.30	9.05	2000	15.74	2.0142	10538	0.7584
24.00	11.75	1920	13.48	2.2579	11812	0.7461
24.10	11.85	1920	13.48	2.2579	11812	0.7429
24.65	12.40	1920	13.23	2.3005	12035	0.7400
24.65	12.40	1930	13.14	2.3283	12181	0.7489
25.20	12.95	1860	12.62	2.3363	12223	0.7354
25.20	12.95	1995	13.31	2.3760	12430	0.7478
25.75	13.50	1940	12.88	2.3876	12491	0.7360
25.80	13.55	1940	12.86	2.3914	12511	0.7358
26.50	14.25	2120	13.95	2.4090	12603	0.7228
26.50	14.25	2010	13.03	2.4453	12793	0.7337
26.90	14.65	1820	11.54	2.5001	13079	0.7398
26.90	14.65	1860	11.80	2.4987	13072	0.7394
27.20	14.95	1895	12.04	2.4950	13053	0.7309
27.20	14.95	1930	12.20	2.5077	13120	0.7346
28.00	15.75	2200	13.68	2.5493	13337	0.7276
28.05	15.80	2215	13.88	2.5297	13234	0.7208
28.70	16.45	1990	12.22	2.5815	13505	0.7209
28.75	16.50	1910	11.48	2.6374	13798	0.7364
29.45	17.20	2115	12.77	2.6254	13735	0.7170
29.50	17.25	1940	11.53	2.6672	13954	0.7274
30.05	17.80	2125	12.56	2.6820	14031	0.7200
30.10	17.85	1975	11.52	2.7177	14218	0.7286
30.95	18.70	2150	12.48	2.7309	14287	0.7153
31.00	18.75	2070	11.81	2.7785	14536	0.7268
31.85	19.60	2070	11.51	2.8509	14915	0.7294
31.85	19.60	1995	11.13	2.8414	14865	0.7269
32.40	20.15	2010	11.18	2.8500	14910	0.7191
32.40	20.15	2005	11.09	2.8659	14994	0.7231
33.40	21.15	2000	10.65	2.9769	15574	0.7332
33.40	21.15	2040	10.91	2.9641	15507	0.7300

TABLE A6-13(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
34.60	22.35	2190	11.49	3.0214	15807	0.7239
34.65	22.40	2260	11.80	3.0361	15884	0.7266
35.65	23.40	2175	11.22	3.0729	16077	0.7195
35.70	23.45	2115	11.16	3.0042	15717	0.7027
36.80	24.55	2048	10.31	3.1489	16474	0.7198
36.85	24.60	2170	10.99	3.1300	16375	0.7148
37.90	25.65	2130	10.58	3.1914	16696	0.7137
37.95	25.70	2100	10.41	3.1978	16730	0.7145
38.40	26.15	2080	10.13	3.2549	17029	0.7209
38.40	26.15	2105	10.35	3.2240	16867	0.7141

TABLE A6-14

Plate: B08ND
Hole Diameter: 0.4981 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Non Deburred

Date:03/23/93
Liquid Temperature: 56 F
Liquid Density: 999.338 Kg/Cu.m
Liquid Viscosity: 1.207 cp
Zero Point: 12.25 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
38.40	26.15	2105	10.35	3.2240	16867	0.7141
37.55	25.30	2035	9.99	3.2291	16894	0.7271
37.45	25.20	2210	10.87	3.2229	16861	0.7272
36.70	24.45	2010	10.16	3.1361	16407	0.7184
36.65	24.40	2100	10.67	3.1199	16322	0.7154
35.75	23.50	2055	10.49	3.1054	16247	0.7256
35.65	23.40	2000	10.25	3.0931	16182	0.7242
34.80	22.55	1890	9.95	3.0111	15753	0.7182
34.75	22.50	2005	10.46	3.0386	15897	0.7256
33.90	21.65	1960	10.49	2.9619	15495	0.7210
33.85	21.60	2135	11.39	2.9714	15545	0.7242
32.70	20.45	1980	10.88	2.8848	15092	0.7226
32.70	20.45	2055	11.28	2.8879	15109	0.7233
31.70	19.45	2000	11.52	2.7521	14398	0.7068
31.70	19.45	1990	11.09	2.8445	14881	0.7305
30.70	18.45	1950	11.19	2.7624	14452	0.7284
30.65	18.40	2000	11.52	2.7521	14398	0.7267
29.70	17.45	1960	11.44	2.7159	14209	0.7364
29.65	17.40	2080	11.69	2.8205	14756	0.7659
28.85	16.60	1990	11.98	2.6332	13776	0.7320
28.85	16.60	1950	11.92	2.5932	13567	0.7209
28.50	16.25	2005	12.27	2.5903	13552	0.7278
28.45	16.20	1820	11.66	2.4743	12945	0.6963
27.50	15.25	1890	11.76	2.5476	13328	0.7389
27.50	15.25	1830	11.42	2.5402	13289	0.7368
26.50	14.25	1980	12.65	2.4812	12981	0.7445
26.45	14.20	2120	13.70	2.4530	12833	0.7373

TABLE A6-14(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
25.95	13.70	1995	13.13	2.4086	12601	0.7371
25.95	13.70	1960	12.66	2.4542	12839	0.7510
25.00	12.75	1975	13.47	2.3243	12160	0.7373
25.00	12.75	1910	13.13	2.3060	12064	0.7315
24.35	12.10	1885	13.04	2.2915	11988	0.7461
24.30	12.05	1950	13.59	2.2746	11900	0.7422
23.80	11.55	1995	14.16	2.2334	11684	0.7443
23.80	11.55	1970	13.90	2.2467	11754	0.7488
23.40	11.15	1945	13.88	2.2213	11621	0.7535
23.40	11.15	1900	13.69	2.2001	11510	0.7463
23.10	10.85	1920	14.06	2.1647	11325	0.7444
23.10	10.85	1885	13.79	2.1669	11336	0.7451
22.50	10.25	1795	13.48	2.1109	11043	0.7468
22.45	10.20	1970	14.75	2.1172	11076	0.7509
22.05	9.80	1960	14.96	2.0783	10873	0.7519
22.05	9.80	2035	15.57	2.0719	10839	0.7496
21.65	9.40	1975	15.30	2.0463	10705	0.7560
21.65	9.40	2010	15.62	2.0399	10672	0.7536
20.70	8.45	1995	16.34	1.9354	10125	0.7541
20.75	8.50	1970	15.89	1.9653	10282	0.7635
19.65	7.40	1925	16.67	1.8305	9577	0.7622
19.55	7.30	2115	18.60	1.8025	9430	0.7556
18.40	6.15	1990	18.70	1.6869	8825	0.7705
18.35	6.10	1850	17.58	1.6682	8727	0.7650
17.10	4.85	2015	20.99	1.5218	7961	0.7827
17.05	4.80	1680	17.66	1.5080	7889	0.7796
16.00	3.75	1990	23.32	1.3527	7077	0.7912
15.95	3.70	1875	22.01	1.3504	7065	0.7962
14.80	2.55	1970	27.69	1.1278	5900	0.7999
14.80	2.55	1915	26.88	1.1293	5908	0.8010
14.05	1.80	1860	31.13	0.9471	4955	0.7996
14.05	1.80	1850	30.70	0.9563	4997	0.8065
13.00	0.75	1550	36.31	0.6767	3540	0.8850
12.90	0.65	1210	31.55	0.6080	3180	0.8541

TABLE A6-15

Plate: B18ND
Hole Diameter: 0.4981 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Non Deburred

Date:03/27/93
Liquid Temperature: 52 F
Liquid Density: 999.595 Kg/Cu.m
Liquid Viscosity: 1.289 cp
Zero Point: 12.40 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.25	0.85	1090	31.74	0.5444	2699	0.6688
13.25	0.85	1020	30.63	0.5279	2617	0.6485
14.10	1.70	1745	31.24	0.8855	4391	0.7692
14.05	1.65	1700	30.63	0.8798	4363	0.7758
14.90	2.50	1860	26.58	1.1093	5501	0.7946
14.95	2.55	1970	28.02	1.1145	5527	0.7905
16.00	3.60	1960	23.62	1.3164	6523	0.7852
16.00	3.60	1975	23.77	1.3171	6532	0.7863
16.85	4.45	2105	23.31	1.4315	7099	0.7686
16.90	4.50	1800	19.97	1.4288	7086	0.7629
17.90	5.50	1975	19.79	1.5820	7845	0.7641
17.95	5.55	1960	19.57	1.5876	7873	0.7633
18.85	6.45	2115	20.15	1.6639	8251	0.7421
18.90	6.50	1960	18.32	1.6960	8410	0.7535
19.60	7.20	1995	17.83	1.7737	8796	0.7487
19.60	7.20	1935	17.35	1.7679	8767	0.7463
20.30	7.90	2010	17.08	1.8655	9251	0.7518
20.35	7.95	1960	16.63	1.8683	9265	0.7505
21.15	8.75	2140	17.46	1.9429	9635	0.7440
21.20	8.80	2015	16.41	1.9465	9653	0.7432
21.80	9.40	2185	17.22	2.0114	9975	0.7431
21.80	9.40	2060	16.19	2.0072	9954	0.7415
22.60	10.20	2010	15.11	2.1087	10457	0.7478
22.65	10.25	2060	15.55	2.0898	10364	0.7393
23.70	11.30	2215	16.07	2.1850	10836	0.7362
23.70	11.30	1840	13.26	2.1997	10909	0.7412
24.60	12.20	2000	13.86	2.2874	11344	0.7418

TABLE A6-15(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
24.60	12.20	1910	13.16	2.3007	11410	0.7461
25.75	13.35	2005	13.42	2.3684	11745	0.7342
25.75	13.35	2090	13.95	2.3750	11778	0.7362
26.80	14.40	2200	14.44	2.4151	11977	0.7209
26.90	14.50	1990	12.81	2.4626	12212	0.7325
27.85	15.45	2145	13.64	2.4929	12363	0.7183
27.95	15.55	1980	12.24	2.5643	12717	0.7365
29.05	16.65	1920	11.47	2.6535	13159	0.7366
29.10	16.70	2045	12.38	2.6185	12986	0.7258
29.90	17.50	1990	11.84	2.6643	13213	0.7214
29.90	17.50	1980	11.69	2.6849	13315	0.7270
30.90	18.50	2000	11.50	2.7569	13672	0.7260
30.95	18.55	2090	12.05	2.7494	13635	0.7231
31.90	19.50	1985	11.18	2.8145	13958	0.7219
31.95	19.55	1925	10.78	2.8307	14038	0.7251
32.60	20.20	2235	12.33	2.8734	14250	0.7241
32.70	20.30	1820	10.66	2.7064	13422	0.6804
33.50	21.10	2040	11.03	2.9318	14540	0.7229
33.55	21.15	2060	11.04	2.9579	14669	0.7285
34.50	22.10	2000	10.63	2.9825	14791	0.7186
34.55	22.15	1940	10.27	2.9944	14850	0.7207
35.50	23.10	2040	10.49	3.0628	15288	0.7266
35.53	23.13	2000	10.41	3.0455	15103	0.7173
36.65	24.25	1900	9.74	3.0923	15336	0.7112
36.70	24.30	1985	10.12	3.1093	15420	0.7144
39.20	26.80	2210	10.85	3.2288	16013	0.7064
39.15	26.75	1965	9.58	3.2515	16125	0.7121

TABLE A6-16

Plate: B18ND
Hole Diameter: 0.4981 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Non Deburred

Date:03/27/93
Liquid Temperature: 52 F
Liquid Density: 999.595 Kg/Cu.m
Liquid Viscosity: 1.289 cp
Zero Point: 12.40 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
39.20	26.80	2210	10.85	3.2288	15889	0.7064
39.15	26.75	1965	9.58	3.2515	16000	0.7121
38.75	26.35	1930	9.51	3.2171	15831	0.7099
38.70	26.30	1980	9.66	3.2492	15989	0.7176
37.90	25.50	1990	10.00	3.1545	15523	0.7076
37.85	25.45	2130	10.67	3.1645	15572	0.7105
36.80	24.40	1930	9.69	3.1573	15537	0.7240
36.75	24.35	1945	9.89	3.1175	15341	0.7156
35.50	23.10	1890	9.88	3.0324	14922	0.7146
35.40	23.00	2000	10.56	3.0023	14774	0.7091
34.00	21.60	2145	11.07	3.0716	15115	0.7486
33.90	21.50	2015	10.70	2.9852	14690	0.7292
32.95	20.55	1975	10.89	2.8749	14147	0.7183
32.90	20.50	2015	10.99	2.9064	14302	0.7271
31.90	19.50	2040	11.45	2.8243	13898	0.7244
31.90	19.50	1930	10.88	2.8120	13837	0.7213
31.00	18.60	1980	11.40	2.7532	13548	0.7231
30.95	18.55	1990	11.49	2.7455	13510	0.7220
29.65	17.25	1980	11.79	2.6622	13100	0.7260
29.55	17.15	1960	11.57	2.6717	13147	0.7307
28.55	16.15	1900	11.56	2.6054	12821	0.7343
28.45	16.05	1825	11.04	2.6206	12896	0.7409
27.55	15.15	1860	12.19	2.4188	11902	0.7039
27.60	15.20	1840	11.57	2.5210	12405	0.7324
26.55	14.15	1900	12.38	2.4329	11972	0.7326
26.55	14.15	1895	12.37	2.4284	11950	0.7312
25.25	12.85	1970	13.48	2.3166	11400	0.7320

TABLE A6-16(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
25.20	12.80	2045	13.95	2.3238	11435	0.7357
24.10	11.70	1910	13.52	2.2394	11020	0.7416
24.00	11.60	1905	13.56	2.2270	10959	0.7406
23.10	10.70	1945	14.38	2.1441	10551	0.7424
23.10	10.70	1975	14.53	2.1547	10603	0.7461
22.15	9.75	1960	15.10	2.0576	10125	0.7464
22.10	9.70	2000	15.57	2.0362	10020	0.7405
21.45	9.05	1980	15.88	1.9765	9726	0.7442
21.40	9.00	1970	15.77	1.9802	9744	0.7476
20.60	8.20	1920	15.98	1.9046	9372	0.7534
20.55	8.15	1885	15.81	1.8900	9300	0.7499
20.00	7.60	1945	16.98	1.8158	8935	0.7460
19.95	7.55	1970	17.24	1.8114	8913	0.7467
19.20	6.80	1920	17.70	1.7195	8461	0.7469
19.15	6.75	1890	17.41	1.7209	8468	0.7502
18.80	6.40	1860	17.57	1.6781	8258	0.7513
17.90	5.50	1880	19.00	1.5685	7718	0.7575
17.90	5.50	1940	19.77	1.5555	7654	0.7513
16.10	3.70	1840	22.34	1.3056	6425	0.7688
16.10	3.70	1805	21.72	1.3174	6482	0.7757
15.40	3.00	1860	25.31	1.1649	5732	0.7618
15.40	3.00	1820	24.62	1.1718	5766	0.7663
14.30	1.90	1840	31.31	0.9316	4584	0.7665
14.30	1.90	1810	30.84	0.9304	4578	0.7645
13.50	1.10	1240	30.77	0.6388	3143	0.6899
13.45	1.05	1230	30.56	0.6380	3139	0.7052

TABLE A6-17

Plate: B08DS
Hole Diameter: 0.4987 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Deburred Surface

Date:03/28/93
Liquid Temperature: 54 F
Liquid Density: 999.474 Kg/Cu.m
Liquid Viscosity: 1.249 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.55	1.15	1640	31.86	0.8160	4136	0.8598
13.65	1.25	1645	30.53	0.8541	4329	0.8632
14.40	2.00	1960	29.33	1.0593	5369	0.8464
14.40	2.00	1960	29.38	1.0575	5360	0.8449
15.25	2.85	1975	25.30	1.2375	6272	0.8283
15.25	2.85	2000	25.53	1.2418	6295	0.8312
16.05	3.65	2045	23.02	1.4082	7138	0.8329
16.10	3.70	1940	21.90	1.4042	7118	0.8249
17.10	4.70	2025	20.55	1.5621	7918	0.8141
17.15	4.75	1930	19.51	1.5681	7949	0.8130
18.15	5.75	1935	17.93	1.7107	8672	0.8061
18.15	5.75	1955	18.02	1.7198	8718	0.8104
19.00	6.60	1965	17.04	1.8280	9266	0.8040
19.00	6.60	1970	17.16	1.8198	9225	0.8004
19.65	7.25	1965	16.11	1.9335	9801	0.8114
19.70	7.30	1965	16.18	1.9252	9759	0.8061
20.85	8.45	1970	15.27	2.0451	10367	0.7949
20.85	8.45	1985	15.40	2.0433	10357	0.7942
21.75	9.35	1910	14.01	2.1611	10955	0.7986
21.75	9.35	1990	14.62	2.1577	10937	0.7973
22.35	9.95	1955	14.11	2.1964	11133	0.7868
22.40	10.00	2020	14.39	2.2252	11280	0.7951
23.60	11.20	2010	13.63	2.3377	11850	0.7893
23.60	11.20	1960	13.17	2.3471	11898	0.7925
24.50	12.10	1960	12.68	2.4503	12421	0.7959
24.45	12.05	1970	12.86	2.4283	12309	0.7904
25.75	13.35	1980	12.32	2.5476	12914	0.7879

TABLE A6-17(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
25.75	13.35	2205	13.84	2.5256	12802	0.7810
26.90	14.50	2020	12.16	2.6333	13348	0.7814
26.90	14.50	1990	11.92	2.6464	13415	0.7853
28.25	15.85	1985	11.31	2.7822	14103	0.7896
28.25	15.85	1990	11.39	2.7696	14039	0.7861
29.40	17.00	2010	11.12	2.8653	14525	0.7852
29.40	17.00	2030	11.26	2.8579	14487	0.7832
30.65	18.25	2005	10.87	2.9239	14822	0.7734
30.65	18.25	1990	10.48	3.0101	15258	0.7962
31.75	19.35	1960	10.26	3.0283	15350	0.7779
31.80	19.40	1960	10.09	3.0793	15609	0.7900
32.70	20.30	1990	10.20	3.0927	15677	0.7756
32.70	20.30	1940	10.01	3.0722	15573	0.7705
33.30	20.90	1960	9.76	3.1834	16137	0.7868
33.35	20.95	2055	10.34	3.1505	15970	0.7777
34.20	21.80	2020	9.95	3.2182	16313	0.7788
34.20	21.80	1980	9.78	3.2093	16268	0.7767
34.95	22.55	2010	9.74	3.2713	16583	0.7784
34.95	22.55	1960	9.47	3.2809	16631	0.7807
35.30	22.90	2000	9.60	3.3025	16741	0.7798
35.30	22.90	2040	9.71	3.3304	16882	0.7864

TABLE A6-18

Plate: B08DS
Hole Diameter: 0.4987 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Deburred Surface

Date:03/28/93
Liquid Temperature: 54 F
Liquid Density: 999.474 Kg/Cu.m
Liquid Viscosity: 1.249 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
35.30	22.90	2000	9.60	3.3025	16741	0.7798
35.30	22.90	2040	9.71	3.3304	16882	0.7864
34.20	21.80	1950	9.49	3.2573	16511	0.7883
34.15	21.75	1990	9.78	3.2255	16350	0.7815
32.80	20.40	1990	10.22	3.0866	15646	0.7722
32.80	20.40	2000	10.27	3.0870	15649	0.7723
31.80	19.40	1895	9.85	3.0497	15459	0.7824
31.80	19.40	1880	9.79	3.0441	15431	0.7809
30.85	18.45	1980	10.56	2.9723	15067	0.7819
30.85	18.45	2075	11.18	2.9421	14914	0.7740
29.80	17.40	1960	10.80	2.8768	14583	0.7793
29.65	17.25	1950	10.64	2.9052	14727	0.7904
28.50	16.10	1960	11.06	2.8092	14240	0.7911
28.45	16.05	2050	11.74	2.7680	14031	0.7807
27.40	15.00	1995	11.73	2.6961	13666	0.7866
27.40	15.00	1985	11.71	2.6871	13621	0.7840
26.60	14.20	2010	12.16	2.6203	13282	0.7857
26.50	14.10	2025	12.18	2.6355	13359	0.7931
25.50	13.10	2035	12.84	2.5124	12735	0.7843
25.40	13.00	2235	14.25	2.4863	12603	0.7792
24.45	12.05	1965	12.59	2.4741	12541	0.8053
24.40	12.00	1950	12.83	2.4093	12213	0.7859
23.50	11.10	2030	13.96	2.3068	11693	0.7823
23.40	11.00	2020	13.76	2.3271	11796	0.7928
22.60	10.20	1985	13.98	2.2508	11409	0.7963
22.55	10.15	1900	13.47	2.2360	11334	0.7930
21.80	9.40	1950	14.17	2.1815	11058	0.8040

TABLE A6-18(CONTD.)

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
21.75	9.35	1920	14.09	2.1601	10950	0.7982
21.00	8.60	2015	15.45	2.0674	10480	0.7966
21.00	8.60	1980	15.12	2.0759	10523	0.7998
20.30	7.90	1990	16.11	1.9581	9926	0.7872
20.35	7.95	1970	15.80	1.9765	10019	0.7921
19.40	7.00	1940	16.49	1.8649	9453	0.7965
19.35	6.95	1960	16.54	1.8785	9522	0.8051
18.60	6.20	1930	17.27	1.7715	8980	0.8039
18.55	6.15	1870	16.60	1.7857	9052	0.8136
17.75	5.35	1955	18.82	1.6467	8347	0.8044
17.70	5.30	2000	19.18	1.6530	8379	0.8113
16.80	4.40	1970	20.63	1.5137	7673	0.8154
16.80	4.40	1990	20.69	1.5247	7728	0.8213
16.20	3.80	1910	21.53	1.4063	7128	0.8151
15.30	2.90	2005	25.22	1.2602	6388	0.8362
15.25	2.85	1625	20.52	1.2553	6363	0.8402
14.50	2.10	1785	25.99	1.0887	5518	0.8489
14.45	2.05	1760	25.79	1.0818	5483	0.8537
13.65	1.25	1690	30.56	0.8766	4443	0.8860
13.60	1.20	1690	30.63	0.8746	4433	0.9022

TABLE A6-19

Plate: B18DS
Hole Diameter: 0.4987 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Deburred Surface

Date:03/30/93
Liquid Temperature: 55.5 F
Liquid Density: 999.364 Kg/Cu.m
Liquid Viscosity: 1.222 cp
Zero Point: 12.40 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.80	1.40	1530	31.73	0.7644	4084	0.7300
13.80	1.40	1500	31.39	0.7575	4048	0.7234
14.80	2.40	1880	28.96	1.0291	5499	0.7506
14.80	2.40	1970	30.54	1.0225	5464	0.7458
15.50	3.10	1845	25.20	1.1606	6202	0.7448
15.50	3.10	1820	24.95	1.1563	6179	0.7421
16.80	4.40	1790	20.80	1.3642	7290	0.7349
16.80	4.40	1910	22.13	1.3682	7311	0.7370
19.10	6.70	1930	18.54	1.6502	8818	0.7204
19.10	6.70	1950	18.74	1.6495	8815	0.7201
21.90	9.50	1920	15.56	1.9560	10453	0.7171
25.40	13.00	1865	13.21	2.2380	11960	0.7014
25.60	13.20	1960	13.70	2.2679	12119	0.7053
28.90	16.50	1950	12.56	2.4611	13152	0.6846
29.00	16.60	1910	12.09	2.5043	13383	0.6945
30.95	18.55	1940	11.72	2.6240	14022	0.6884
30.95	18.55	1940	11.66	2.6375	14094	0.6919
33.00	20.60	2225	12.96	2.7215	14544	0.6775
33.10	20.70	1980	11.25	2.7900	14909	0.6929
35.15	22.75	2190	12.06	2.8786	15383	0.6819
35.30	22.90	1965	10.74	2.9003	15499	0.6848
37.60	25.20	1900	9.78	3.0796	16457	0.6932
37.60	25.20	1940	10.02	3.0691	16401	0.6908
40.70	28.30	2010	9.95	3.2023	17113	0.6802
40.75	28.35	1960	9.66	3.2163	17188	0.6826
41.55	29.15	1990	9.69	3.2555	17397	0.6813
41.60	29.20	2000	9.94	3.1895	17045	0.6669

TABLE A6-20

Plate: B18DS
Hole Diameter: 0.4987 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Deburred Surface

Date:03/30/93
Liquid Temperature: 55.5 F
Liquid Density: 999.364 Kg/Cu.m
Liquid Viscosity: 1.222 cp
Zero Point: 12.40 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
41.60	29.20	2000	9.94	3.1895	16541	0.6669
39.40	27.00	1945	9.80	3.1461	16316	0.6841
39.40	27.00	1965	10.03	3.1056	16106	0.6753
37.15	24.75	2050	10.87	2.9896	15504	0.6790
37.10	24.70	1960	10.34	3.0048	15583	0.6832
37.05	24.65	1950	10.14	3.0485	15809	0.6938
36.70	24.30	1920	10.14	3.0016	15566	0.6880
36.70	24.30	1950	10.38	2.9780	15444	0.6826
35.25	22.85	1950	10.67	2.8970	15024	0.6848
35.20	22.80	1880	10.25	2.9075	15078	0.6880
35.20	22.80	1870	10.11	2.9321	15206	0.6938
31.00	18.60	2030	12.26	2.6248	13612	0.6877
28.05	15.65	1960	13.02	2.3863	12375	0.6816
27.80	15.40	1950	13.02	2.3741	12312	0.6836
24.00	11.60	1920	14.16	2.1494	11147	0.7131
23.95	11.55	1990	14.74	2.1401	11099	0.7115
21.80	9.40	1920	15.73	1.9349	10034	0.7131
21.75	9.35	1970	16.02	1.9493	10109	0.7203
19.30	6.90	1960	18.69	1.6624	8621	0.7151
19.30	6.90	1930	18.44	1.6591	8604	0.7137
18.00	5.60	1950	20.45	1.5116	7839	0.7217
16.55	4.15	1920	22.83	1.3332	6914	0.7394
16.50	4.10	1960	23.12	1.3439	6969	0.7499
14.70	2.30	1690	26.54	1.0094	5235	0.7521
14.60	2.20	1900	29.59	1.0179	5278	0.7754
13.60	1.20	1390	30.29	0.7274	3772	0.7503
13.60	1.20	1420	30.88	0.7289	3780	0.7519

TABLE A6-21

Plate: C08ND
Hole Diameter: 0.4970 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/04/93
Liquid Temperature: 55 F
Liquid Density: 999.402 Kg/Cu.m
Liquid Viscosity: 1.244 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
13.55	1.15	1560	31.16	0.7936	4098	0.8419
13.55	1.15	1440	28.64	0.7970	4116	0.8456
14.25	1.85	1920	31.16	0.9768	5044	0.8170
14.25	1.85	1910	30.94	0.9786	5054	0.8185
15.10	2.70	1990	26.66	1.1833	6111	0.8192
15.10	2.70	1800	24.18	1.1800	6094	0.8170
16.25	3.85	1910	22.16	1.3663	7056	0.7922
16.25	3.85	1790	20.72	1.3695	7072	0.7940
18.95	6.55	1830	16.96	1.7104	8833	0.7603
19.00	6.60	1920	17.44	1.7452	9013	0.7728
20.45	8.05	1955	16.50	1.8782	9700	0.7531
20.45	8.05	1900	16.06	1.8754	9685	0.7520
22.30	9.90	1840	14.20	2.0541	10608	0.7427
22.30	9.90	1940	15.02	2.0475	10574	0.7403
24.50	12.10	1920	13.35	2.2798	11774	0.7456
24.50	12.10	1930	13.48	2.2696	11721	0.7423
26.95	14.55	1890	12.13	2.4699	12756	0.7367
26.95	14.55	1950	12.47	2.4789	12802	0.7393
29.65	17.25	1965	11.48	2.7133	14013	0.7432
29.65	17.25	1920	11.31	2.6911	13898	0.7371
32.60	20.20	2010	11.13	2.8628	14785	0.7247
32.70	20.30	1910	10.56	2.8672	14808	0.7240
35.75	23.35	1860	9.69	3.0428	15715	0.7164
35.75	23.35	1950	10.07	3.0697	15853	0.7227
38.75	26.35	1900	9.24	3.2596	16834	0.7224
38.80	26.40	1925	9.31	3.2777	16928	0.7257

TABLE A6-22

Plate: C08ND
Hole Diameter: 0.4970 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/04/93
Liquid Temperature: 55 F
Liquid Density: 999.402 Kg/Cu.m
Liquid Viscosity: 1.244 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	VOLUME COLLECTED ML.	TIME SEC	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
38.80	26.40	1925	9.31	3.2777	16748	0.7257
35.80	23.40	1940	9.95	3.0907	15793	0.7269
35.80	23.40	1920	9.86	3.0868	15773	0.7260
32.95	20.55	1870	10.22	2.9005	14821	0.7279
32.85	20.45	1940	10.55	2.9150	14895	0.7333
29.50	17.10	1970	11.93	2.6176	13376	0.7202
29.50	17.10	1935	11.61	2.6420	13500	0.7269
26.95	14.55	1950	12.70	2.4340	12437	0.7259
26.90	14.50	1950	12.71	2.4321	12427	0.7266
24.10	11.70	1855	13.07	2.2498	11496	0.7483
24.10	11.70	1980	14.08	2.2292	11391	0.7414
22.05	9.65	1960	15.21	2.0427	10438	0.7481
22.05	9.65	1965	15.44	2.0174	10308	0.7388
19.85	7.45	1980	17.35	1.8090	9244	0.7540
19.80	7.40	1940	17.16	1.7921	9157	0.7495
17.60	5.20	1845	19.06	1.5345	7841	0.7656
17.50	5.10	1955	20.27	1.5289	7812	0.7702
15.70	3.30	1910	23.99	1.2621	6449	0.7904
15.65	3.25	2015	25.47	1.2541	6408	0.7914
14.40	2.00	2000	30.91	1.0257	5241	0.8251
14.40	2.00	1760	27.24	1.0242	5233	0.8239
13.50	1.10	1585	31.41	0.7999	4087	0.8677
13.50	1.10	1610	32.17	0.7933	4053	0.8606

TABLE A6-23

Plate: D08ND
Hole Diameter: 0.4992 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/05/93
Liquid Temperature: 56 F
Liquid Density: 999.338 Kg/Cu.m
Liquid Viscosity: 1.212 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.40	1.00	0.74	3863	0.8345
13.40	1.00	0.74	3863	0.8345
14.15	1.75	0.94	4907	0.8013
14.85	2.45	1.11	5794	0.7997
15.40	3.00	1.21	6316	0.7878
15.90	3.50	1.30	6786	0.7836
16.75	4.35	1.45	7569	0.7840
17.95	5.55	1.60	8352	0.7659
19.00	6.60	1.75	9135	0.7682
20.40	8.00	1.95	10179	0.7774
21.60	9.20	2.05	10701	0.7622
23.90	11.50	2.24	11693	0.7449
25.70	13.30	2.39	12476	0.7390
27.65	15.25	2.55	13311	0.7364
30.35	17.95	2.73	14251	0.7266
33.10	20.70	2.91	15191	0.7213
36.20	23.80	3.19	16652	0.7374
36.20	23.80	3.21	16757	0.7420
38.20	25.80	3.29	17174	0.7304
38.25	25.85	3.30	17227	0.7319

TABLE A6-24

Plate: D08ND
Hole Diameter: 0.4992 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/05/93
Liquid Temperature: 56 F
Liquid Density: 999.338 Kg/Cu.m
Liquid Viscosity: 1.212 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
38.25	25.85	3.30	16968	0.7319
35.40	23.00	3.06	15734	0.7195
32.90	20.50	2.89	14860	0.7198
30.70	18.30	2.72	13986	0.7170
27.90	15.50	2.53	13009	0.7247
25.50	13.10	2.34	12032	0.7291
23.45	11.05	2.15	11056	0.7294
21.00	8.60	1.92	9872	0.7383
19.20	6.80	1.73	8895	0.7481
17.50	5.10	1.50	7712	0.7490
16.05	3.65	1.31	6735	0.7732
15.10	2.70	1.13	5810	0.7755
14.00	1.60	0.89	4576	0.7934
13.40	1.00	0.69	3547	0.7781

TABLE A6-25

Plate: E08ND
Hole Diameter: 0.5006 in.
Plate Thickness: 14 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/06/93
Liquid Temperature: 55.7 F
Liquid Density: 999.538 Kg/Cu.m
Liquid Viscosity: 1.218 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.40	1.00	0.69	3574	0.7737
13.85	1.45	0.89	4610	0.8288
14.40	2.00	1.04	5387	0.8246
15.00	2.60	1.19	6164	0.8276
15.80	3.40	1.34	6941	0.8149
16.95	4.55	1.51	7821	0.7938
17.80	5.40	1.63	8443	0.7866
19.20	6.80	1.79	9271	0.7697
20.50	8.10	1.95	10100	0.7683
22.05	9.65	2.10	10877	0.7581
23.70	11.30	2.26	11706	0.7539
25.55	13.15	2.42	12535	0.7483
27.40	15.00	2.56	13260	0.7412
29.20	16.80	2.70	13985	0.7387
31.50	19.10	2.86	14814	0.7338
33.30	20.90	2.97	15384	0.7285
35.00	22.60	3.12	16161	0.7360
36.90	24.50	3.32	17197	0.7522
36.90	24.50	3.32	17197	0.7522

TABLE A6-26

Plate: E08ND
Hole Diameter: 0.5006 in.
Plate Thickness: 14 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/06/93
Liquid Temperature: 55.7 F
Liquid Density: 999.538 Kg/Cu.m
Liquid Viscosity: 1.218 cp
Zero Point: 12.40 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
36.95	24.55	3.31	16972	0.7491
36.90	24.50	3.30	16920	0.7476
34.70	22.30	3.14	16100	0.7456
34.70	22.30	3.14	16100	0.7456
32.40	20.00	2.91	14921	0.7297
30.40	18.00	2.76	14152	0.7295
28.45	16.05	2.62	13434	0.7334
26.50	14.10	2.47	12665	0.7376
24.75	12.35	2.32	11895	0.7403
22.60	10.20	2.13	10921	0.7479
20.90	8.50	1.96	10050	0.7539
19.20	6.80	1.77	9075	0.7611
17.60	5.20	1.57	8050	0.7721
15.50	3.10	1.25	6409	0.7961
14.20	1.80	1.01	5178	0.8442
13.55	1.15	0.78	3999	0.8156

TABLE A6-27

Plate: E15ND
Hole Diameter: 0.4999 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/07/93
Liquid Temperature: 55.5 F
Liquid Density: 999.364 Kg/Cu.m
Liquid Viscosity: 1.222 cp
Zero Point: 12.60 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.50	0.90	0.74	3799	0.8772
14.10	1.50	0.95	4878	0.8723
14.75	2.15	1.15	5904	0.8820
15.55	2.95	1.31	6726	0.8577
16.50	3.90	1.48	7599	0.8427
17.60	5.00	1.61	8266	0.8097
19.00	6.40	1.80	9242	0.8001
20.85	8.25	1.97	10115	0.7713
22.35	9.75	2.14	10988	0.7707
23.90	11.30	2.28	11707	0.7627
25.75	13.15	2.45	12580	0.7597
28.30	15.70	2.64	13555	0.7492
30.90	18.30	2.81	14428	0.7387
33.90	21.30	2.99	15352	0.7285
36.40	23.80	3.18	16328	0.7330
38.10	25.50	3.29	16893	0.7326

TABLE A6-28

Plate: E15ND
Hole Diameter: 0.4999 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/07/93
Liquid Temperature: 55.5 F
Liquid Density: 999.364 Kg/Cu.m
Liquid Viscosity: 1.222 cp
Zero Point: 12.60 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
38.10	25.50	3.29	17021	0.7326
35.50	22.90	3.07	15883	0.7214
32.50	19.90	2.90	15003	0.7310
30.10	17.50	2.76	14279	0.7419
28.10	15.50	2.61	13503	0.7455
26.10	13.50	2.46	12727	0.7529
24.50	11.90	2.32	12003	0.7563
22.25	9.65	2.12	10968	0.7674
20.55	7.95	1.95	10088	0.7777
19.30	6.70	1.79	9261	0.7776
17.40	4.80	1.55	8019	0.7956
16.40	3.80	1.42	7346	0.8191
15.40	2.80	1.26	6518	0.8468
14.35	1.75	1.00	5173	0.8501
13.40	0.80	0.80	4139	1.0058

TABLE A6-29

Plate: D05ND
Hole Diameter: 0.4971 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/09/93
Liquid Temperature: 55.3 F
Liquid Density: 999.377 Kg/Cu.m
Liquid Viscosity: 1.225 cp
Zero Point: 12.50 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.80	1.30	0.84	4291	0.8378
14.40	1.90	1.01	5160	0.8333
14.95	2.45	1.15	5875	0.8355
15.90	3.40	1.33	6794	0.8203
16.95	4.45	1.49	7612	0.8032
18.30	5.80	1.67	8531	0.7886
20.30	7.80	1.91	9758	0.7777
22.20	9.70	2.08	10626	0.7595
24.10	11.60	2.25	11495	0.7513
26.75	14.25	2.47	12619	0.7441
28.25	15.75	2.59	13232	0.7422
30.10	17.60	2.72	13896	0.7373
32.70	20.20	2.88	14713	0.7287
35.00	22.50	3.03	15480	0.7264
38.20	25.70	3.30	16859	0.7403
38.30	25.80	3.33	17012	0.7456

TABLE A6-30

Plate: D05ND
Hole Diameter: 0.4971 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/09/93
Liquid Temperature: 55.3 F
Liquid Density: 999.377 Kg/Cu.m
Liquid Viscosity: 1.225 cp
Zero Point: 12.50 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
38.35	25.85	3.33	17273	0.7448
37.50	25.00	3.23	16754	0.7346
36.50	23.00	3.10	16080	0.7351
33.30	20.80	2.98	15457	0.7431
31.20	18.70	2.80	14524	0.7363
29.00	16.50	2.62	13590	0.7335
27.20	14.70	2.48	12864	0.7356
24.75	12.25	2.29	11878	0.7441
22.95	10.45	2.13	11048	0.7493
20.85	8.35	1.92	9959	0.7556
19.25	6.75	1.73	8973	0.7572
17.80	5.30	1.57	8143	0.7756
16.50	4.00	1.40	7262	0.7961
15.50	3.00	1.23	6380	0.8076
14.60	2.10	1.05	5446	0.8240
13.55	1.05	0.77	3994	0.8546

TABLE A6-31

Plate: B05ND
Hole Diameter: 0.4979 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/11/93
Liquid Temperature: 56.5 F
Liquid Density: 999.299 Kg/Cu.m
Liquid Viscosity: 1.203 cp
Zero Point: 12.70 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.50	0.80	0.78	4113	0.9885
14.05	1.35	0.93	4904	0.9073
14.80	2.10	1.12	5906	0.8761
15.60	2.90	1.27	6697	0.8454
16.60	3.90	1.42	7488	0.8151
17.75	5.05	1.56	8226	0.7869
18.95	6.25	1.72	9070	0.7799
20.30	7.60	1.87	9861	0.7689
21.70	9.00	2.00	10546	0.7557
23.45	10.75	2.14	11285	0.7399
25.20	12.50	2.29	12076	0.7342
27.15	14.45	2.43	12814	0.7246
29.10	16.40	2.58	13605	0.7222
31.15	18.45	2.71	14290	0.7152
33.40	20.70	2.89	15240	0.7200
33.45	20.75	2.89	15240	0.7192
35.75	23.05	3.00	15820	0.7083
35.75	23.05	3.03	15978	0.7154
37.65	24.95	3.12	16453	0.7081
37.70	25.00	3.15	16611	0.7141
40.15	27.45	3.28	17296	0.7097

TABLE A6-32

Plate: B05ND
Hole Diameter: 0.4979 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/11/93
Liquid Temperature: 56.5 F
Liquid Density: 999.299 Kg/Cu.m
Liquid Viscosity: 1.203 cp
Zero Point: 12.70 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
40.15	27.45	3.28	16909	0.7097
38.05	25.35	3.13	16136	0.7047
36.15	23.45	3.04	15672	0.7116
36.00	23.30	3.04	15672	0.7139
33.80	21.10	2.88	14847	0.7107
31.80	19.10	2.73	14074	0.7081
30.00	17.30	2.61	13455	0.7113
28.25	15.55	2.49	12836	0.7158
26.40	13.70	2.35	12115	0.7197
24.80	12.10	2.22	11444	0.7234
23.00	10.30	2.08	10723	0.7347
21.00	8.30	1.89	9743	0.7437
19.00	6.30	1.67	8609	0.7542
17.15	4.45	1.45	7475	0.7792
15.50	2.80	1.22	6289	0.8265
14.45	1.75	0.99	5103	0.8483
13.50	0.80	0.77	3969	0.9759

TABLE A6-33

Plate: B05DS
Hole Diameter: 0.4990 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Deburred Surface

Date:04/12/93
Liquid Temperature: 58 F
Liquid Density: 999.188 Kg/Cu.m
Liquid Viscosity: 1.177 cp
Zero Point: 12.65 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.50	0.85	0.78	4196	0.9548
14.00	1.35	0.97	5219	0.9422
14.50	1.85	1.10	5918	0.9127
15.50	2.85	1.33	7156	0.8891
16.95	4.30	1.55	8340	0.8436
18.50	5.85	1.74	9362	0.8119
20.00	7.35	1.90	10223	0.7909
21.40	8.75	2.05	11030	0.7821
22.85	10.20	2.21	11891	0.7809
24.65	12.00	2.36	12698	0.7689
26.25	13.60	2.51	13505	0.7681
28.40	15.75	2.67	14366	0.7593
31.10	18.45	2.86	15388	0.7514
33.40	20.75	3.06	16465	0.7581
33.40	20.75	3.08	16572	0.7631
34.90	22.25	3.19	17164	0.7632
34.90	22.25	3.21	17272	0.7680
37.20	24.55	3.36	18079	0.7653
37.20	24.55	3.37	18133	0.7676

TABLE A6-34

Plate: B05DS
Hole Diameter: 0.4990 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Deburred Surface

Date:04/12/93
Liquid Temperature: 58 F
Liquid Density: 999.188 Kg/Cu.m
Liquid Viscosity: 1.177 cp
Zero Point: 12.65 cm.
Flow Parallel to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
37.20	24.55	3.33	17566	0.7585
37.20	24.55	3.34	17619	0.7608
35.20	22.55	3.23	17038	0.7676
35.20	22.55	3.24	17091	0.7700
33.50	20.85	3.07	16194	0.7588
33.50	20.85	3.11	16405	0.7687
30.50	17.85	2.82	14876	0.7533
28.35	15.70	2.64	13926	0.7519
26.35	13.70	2.49	13135	0.7592
24.00	11.35	2.30	12132	0.7705
22.20	9.55	2.13	11236	0.7779
20.70	8.05	1.98	10444	0.7876
19.20	6.55	1.81	9548	0.7982
17.50	4.85	1.61	8493	0.8251
16.10	3.45	1.41	7438	0.8567
14.90	2.25	1.21	6382	0.9104
14.10	1.45	0.99	5222	0.9279
13.50	0.85	0.80	4220	0.9793

TABLE A6-35

Plate: C15ND
Hole Diameter: 0.4982 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/12/93
Liquid Temperature: 56.5 F
Liquid Density: 999.299 Kg/Cu.m
Liquid Viscosity: 1.203 cp
Zero Point: 12.6 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.60	1.00	0.79	4163	0.8944
14.20	1.60	0.99	5217	0.8861
14.80	2.20	1.15	6060	0.8778
15.35	2.75	1.30	6851	0.8876
16.40	3.80	1.47	7747	0.8538
17.40	4.80	1.61	8485	0.8320
18.65	6.05	1.77	9328	0.8147
20.35	7.75	1.96	10329	0.7971
21.75	9.15	2.12	11172	0.7935
22.95	10.35	2.25	11858	0.7918
24.80	12.20	2.42	12753	0.7844
26.70	14.10	2.57	13544	0.7749
28.60	16.00	2.72	14335	0.7699
31.15	18.55	2.87	15125	0.7545
33.60	21.00	3.03	15968	0.7486
33.60	21.00	3.07	16179	0.7585
35.95	23.35	3.22	16970	0.7545
35.95	23.35	3.24	17075	0.7591
37.40	24.80	3.30	17391	0.7503
37.40	24.80	3.30	17391	0.7503

TABLE A6-36

Plate: C15ND
Hole Diameter: 0.4982 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/12/93
Liquid Temperature: 56.5 F
Liquid Density: 999.299 Kg/Cu.m
Liquid Viscosity: 1.203 cp
Zero Point: 12.6 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
37.40	24.80	3.30	17587	0.7503
35.95	23.35	3.20	17054	0.7498
35.90	23.30	3.22	17161	0.7553
33.50	20.90	3.05	16255	0.7554
30.65	18.05	2.84	15136	0.7568
28.30	15.70	2.68	14283	0.7658
25.90	13.30	2.51	13377	0.7792
24.30	11.70	2.36	12578	0.7812
22.50	9.90	2.19	11671	0.7880
20.80	8.20	2.02	10765	0.7987
19.40	6.80	1.86	9913	0.8076
17.45	4.85	1.62	8634	0.8329
15.05	2.45	1.25	6662	0.9042
14.20	1.60	1.01	5382	0.9040
13.40	0.80	0.72	3837	0.9114

TABLE A6-37

Plate: B15ND
Hole Diameter: 0.4979 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Non deburred Surface

Date:04/13/93
Liquid Temperature: 57 F
Liquid Density: 999.258 Kg/Cu.m
Liquid Viscosity: 1.194 cp
Zero Point: 12.5 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.90	1.40	0.85	4536	0.8143
15.00	2.50	1.12	5977	0.8030
15.85	3.35	1.29	6884	0.7969
17.00	4.50	1.46	7791	0.7802
18.50	6.00	1.65	8805	0.7636
20.40	7.90	1.87	9979	0.7542
22.40	9.90	2.07	11047	0.7458
24.65	12.15	2.24	11954	0.7285
26.55	14.05	2.39	12754	0.7228
29.35	16.85	2.56	13662	0.7069
31.50	19.00	2.69	14356	0.6996
34.35	21.85	2.86	15263	0.6936
36.60	24.10	3.02	16117	0.6973
36.60	24.10	3.03	16170	0.6997
38.65	26.15	3.16	16864	0.7005
38.65	26.15	3.15	16810	0.6983
40.50	28.00	3.25	17344	0.6962
40.55	28.05	3.25	17344	0.6956

TABLE A6-38

Plate: B15ND
Hole Diameter: 0.4979 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Non deburred Surface

Date:04/13/93
Liquid Temperature: 57 F
Liquid Density: 999.258 Kg/Cu.m
Liquid Viscosity: 1.194 cp
Zero Point: 12.5 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
40.55	28.05	3.25	17267	0.6956
38.45	25.95	3.12	16576	0.6943
38.45	25.95	3.11	16523	0.6921
36.60	24.10	3.00	15938	0.6927
36.55	24.05	3.02	16045	0.6981
34.20	21.70	2.83	15035	0.6887
32.15	19.65	2.71	14398	0.6930
29.50	17.00	2.55	13548	0.7011
27.40	14.90	2.42	12857	0.7107
24.90	12.40	2.25	11954	0.7243
23.10	10.60	2.11	11210	0.7346
20.90	8.40	1.91	10147	0.7470
19.20	6.70	1.71	9085	0.7489
17.00	4.50	1.44	7650	0.7695
15.10	2.60	1.12	5950	0.7674
14.10	1.60	0.92	4887	0.8245

TABLE A6-39

Plate: B15DS
Hole Diameter: 0.4990 in.
Plate Thickness: 12 Gage.
Liquid: Water
Increasing Head
Deburred Surface

Date:04/13/93
Liquid Temperature: 57.7 F
Liquid Density: 999.202 Kg/Cu.m
Liquid Viscosity: 1.182 cp
Zero Point: 12.6 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
13.60	1.00	0.77	4081	0.8690
14.20	1.60	0.96	5089	0.8565
14.80	2.20	1.13	5990	0.8598
15.70	3.10	1.33	7050	0.8525
17.20	4.60	1.56	8270	0.8209
18.95	6.35	1.79	9489	0.8017
20.40	7.80	1.96	10390	0.7920
21.75	9.15	2.11	11185	0.7872
21.80	9.20	2.12	11238	0.7868
23.00	10.40	2.25	11927	0.7874
24.60	12.00	2.40	12723	0.7819
26.70	14.10	2.58	13677	0.7764
28.50	15.90	2.73	14472	0.7727
30.90	18.30	2.91	15426	0.7677
33.00	20.40	3.12	16540	0.7796
33.00	20.40	3.12	16540	0.7796
34.40	21.80	3.20	16964	0.7736
34.40	21.80	3.23	17123	0.7807
36.40	23.80	3.36	17812	0.7773
36.40	23.80	3.36	17812	0.7773

TABLE A6-40

Plate: B15DS
Hole Diameter: 0.4990 in.
Plate Thickness: 12 Gage.
Liquid: Water
Decreasing Head
Deburred Surface

Date:04/13/93
Liquid Temperature: 57.7 F
Liquid Density: 999.202 Kg/Cu.m
Liquid Viscosity: 1.182 cp
Zero Point: 12.6 cm.
Flow Counter to Punch Direction

LIQUID ELEVATION CM	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFFICIENT
36.40	23.80	3.36	17990	0.7773
36.40	23.80	3.32	17776	0.7680
35.00	22.40	3.23	17294	0.7702
35.00	22.40	3.24	17348	0.7726
33.15	20.55	3.09	16545	0.7693
33.05	20.45	3.10	16598	0.7737
31.20	18.60	2.92	15634	0.7641
28.85	16.25	2.75	14724	0.7699
27.00	14.40	2.62	14028	0.7792
25.05	12.45	2.43	13011	0.7772
22.70	10.10	2.22	11886	0.7884
21.10	8.50	2.04	10923	0.7897
19.70	7.10	1.87	10012	0.7920
18.30	5.70	1.70	9102	0.8036
16.75	4.15	1.49	7978	0.8255
14.60	2.00	1.10	5889	0.8778
13.70	1.10	0.82	4390	0.8824

APPENDIX 7

DISTRIBUTOR TROUGH DATA

The data collected from tests on the distributor trough are documented here. Runs 1-3 are not included because they were test runs carried out to familiarize ourselves with the apparatus. All other data are reported here. The inlet flow rate to the trough was measured in gpm using the flow meter. Flow rates through individual orifices were measured in ml/sec using a measuring cylinder and stopwatch. The head was measured in cm. The individual flow rates were added to give a total flow rate was then compared with the flow meter reading. This gave us some idea of the accuracy of the flow meter. Each reading for the head and flow rate was then converted to an orifice coefficient and Reynolds number. Average values were calculated for each run.

TABLE A7-1

Run # 4 **Water Temperature: 71.3 F**
Date: 6/13/93 **Water Density: 997.816 Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.976 cp**
Experimental Condition: Constant Inlet Flow of Water (10.04 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	65.75	1340	33.50	2.95	0.6341	5948	0.8734
2	1	0.3447	62.80	65.80	1330	33.45	3.00	0.6303	5913	0.8609
3	2	0.3458	62.80	65.80	1280	31.97	3.00	0.6347	5935	0.8614
4	2	0.3458	62.80	65.80	1400	35.23	3.00	0.6299	5891	0.8550
5	3	0.3457	31.70	34.75	1275	32.02	3.05	0.6312	5904	0.8501
6	3	0.3457	31.70	34.75	1270	31.63	3.05	0.6365	5954	0.8572
7	4	0.3455	31.70	34.80	1250	31.37	3.10	0.6317	5912	0.8448
8	4	0.3455	31.70	34.80	1270	31.89	3.10	0.6313	5909	0.8443
9	5	0.3462	17.60	20.55	1260	31.67	2.95	0.6307	5891	0.8612
10	5	0.3462	17.60	20.55	1270	32.12	2.95	0.6268	5854	0.8559
11	6	0.3455	17.60	20.60	1250	31.82	3.00	0.6227	5828	0.8466
12	6	0.3455	17.60	20.60	1240	31.57	3.00	0.6226	5828	0.8465
13	7	0.3454	90.20	92.75	1210	32.13	2.55	0.5970	5589	0.8809
14	7	0.3454	90.20	92.75	1250	33.65	2.55	0.5889	5513	0.8689
15	8	0.3462	90.20	92.75	1220	32.22	2.55	0.6002	5607	0.8816
16	8	0.3462	90.20	92.70	1220	32.27	2.50	0.5993	5598	0.8890
17	9	0.3448	1.60		510	40.40	2.63	0.2001	1877	0.2918

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60		570	43.93	2.63	0.2057	1929	0.2999
19	10	0.3457	1.60		640	31.59	2.63	0.3212	3004	0.4658
20	10	0.3457	1.60		550	26.38	2.63	0.3305	3092	0.4794
21	11	0.3464	2.80	5.50	1310	33.52	2.70	0.6195	5783	0.8832
22	11	0.3464	2.80	5.50	1300	33.34	2.70	0.6181	5770	0.8812
23	12	0.3456	2.80	5.50	1310	34.20	2.70	0.6072	5681	0.8697
24	12	0.3456	2.80	5.50	1275	33.57	2.70	0.6021	5633	0.8623
25	13	0.3467	59.90	62.80	1520	39.02	2.90	0.6175	5760	0.8480
26	13	0.3467	59.90	62.80	1530	39.04	2.90	0.6212	5794	0.8531
27	14	0.3445	59.90	62.80	1140	29.35	2.90	0.6157	5780	0.8564
28	14	0.3445	59.90	62.80	1240	32.03	2.90	0.6137	5761	0.8536
29	15	0.3452	29.50	32.40	1280	33.20	2.90	0.6112	5725	0.8466
30	15	0.3452	29.50	32.40	1240	31.88	2.90	0.6166	5776	0.8541
31	16	0.3447	29.50	32.40	1280	33.63	2.90	0.6033	5660	0.8382
32	16	0.3447	29.50	32.40	1250	32.86	2.90	0.6030	5657	0.8377
33	17	0.3455	1.50	4.40	1220	32.02	2.90	0.6040	5653	0.8352
34	17	0.3455	1.50	4.40	1600	42.09	2.90	0.6026	5640	0.8333
35	18	0.3449	1.50	4.30	1340	35.83	2.80	0.5928	5558	0.8372
36	18	0.3449	1.50	4.30	1340	35.74	2.80	0.5943	5572	0.8393
AVERAGE							2.84	0.5763	5394	0.8040

TOTAL IN FLOW 10.3741 GPM

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-2

Run # 5 **Water Temperature: 72.3 F**
Date: 6/14/93 **Water Density: 997.679 Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.958 cp**
Experimental Condition: Constant Inlet Flow of Water (14.28 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.75	69.20	1710	31.45	6.45	0.8619	8237	0.8029
2	1	0.3447	62.75	69.20	1700	31.09	6.45	0.8668	8283	0.8074
3	2	0.3458	62.75	69.20	1780	32.84	6.45	0.8592	8185	0.7953
4	2	0.3458	62.75	69.20	1770	32.63	6.45	0.8599	8191	0.7959
5	3	0.3457	31.75	38.15	1730	31.94	6.40	0.8586	8181	0.7983
6	3	0.3457	31.75	38.15	1760	32.49	6.40	0.8587	8182	0.7984
7	4	0.3455	31.75	38.15	1710	31.49	6.40	0.8608	8207	0.8013
8	4	0.3455	31.75	38.15	1690	31.24	6.40	0.8576	8176	0.7982
9	5	0.3462	17.60	23.85	1700	31.13	6.25	0.8657	8237	0.8121
10	5	0.3462	17.60	23.85	1720	31.59	6.25	0.8631	8212	0.8097
11	6	0.3455	17.60	23.85	1700	31.47	6.25	0.8563	8164	0.8066
12	6	0.3455	17.60	23.85	1680	31.18	6.25	0.8541	8143	0.8045
13	7	0.3454	90.10	96.20	1550	32.13	6.10	0.7647	7293	0.7296
14	7	0.3454	90.10	96.20	1520	31.32	6.10	0.7693	7337	0.7339
15	8	0.3462	90.10	96.20	1500	31.11	6.10	0.7643	7272	0.7258
16	8	0.3462	90.10	96.20	1500	31.07	6.10	0.7653	7282	0.7267
17	9	0.3448	1.60	-	1320	31.84	6.05	0.6572	6278	0.6317

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1290	31.20	6.05	0.6554	6261	0.6300
19	10	0.3457	1.60	-	1420	36.18	6.05	0.6222	5928	0.5950
20	10	0.3457	1.60	-	1310	33.84	6.05	0.6137	5847	0.5868
21	11	0.3464	2.70	8.70	1710	32.58	6.00	0.8320	7912	0.7957
22	11	0.3464	2.70	8.70	1800	33.69	6.00	0.8469	8054	0.8100
23	12	0.3456	2.70	8.70	1710	34.48	6.00	0.7862	7493	0.7554
24	12	0.3456	2.70	8.70	1680	34.09	6.00	0.7812	7446	0.7506
25	13	0.3467	59.90	65.90	1690	31.72	6.00	0.8446	8024	0.8063
26	13	0.3467	59.90	65.90	1860	34.64	6.00	0.8512	8087	0.8126
27	14	0.3445	59.90	65.90	1710	32.17	6.00	0.8426	8057	0.8148
28	14	0.3445	59.90	65.90	1700	31.71	6.00	0.8498	8126	0.8218
29	15	0.3452	29.50	35.50	1760	32.81	6.00	0.8503	8114	0.8189
30	15	0.3452	29.50	35.50	1710	31.91	6.00	0.8495	8106	0.8181
31	16	0.3447	29.50	35.50	1680	31.65	6.00	0.8414	8041	0.8127
32	16	0.3447	29.50	35.50	1800	34.09	6.00	0.8370	7999	0.8084
33	17	0.3455	1.50	7.50	1780	33.37	6.00	0.8456	8062	0.8129
34	17	0.3455	1.50	7.50	1790	33.71	6.00	0.8417	8025	0.8092
35	18	0.3449	1.50	7.50	1760	33.13	6.00	0.8421	8043	0.8124
36	18	0.3449	1.50	7.50	1760	33.11	6.00	0.8426	8048	0.8129
AVERAGE							6.15	0.8144	7800	0.7770
						TOTAL IN FLOW GPM		14.6598		

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-3

Run # 6 — **Water Temperature: 72.3 F**
Date: 6/15/93 — **Water Density: 997.679 Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.958 cp**
Experimental Condition: Constant Inlet Flow of Water (12.16 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.75	67.20	1510	31.81	4.45	0.7525	7191	0.8439
2	1	0.3447	62.75	67.20	1470	31.15	4.45	0.7481	7149	0.8390
3	2	0.3458	62.75	67.20	1500	31.86	4.45	0.7463	7109	0.8317
4	2	0.3458	62.75	67.20	1470	31.24	4.45	0.7459	7105	0.8312
5	3	0.3457	31.75	36.20	1700	36.16	4.45	0.7453	7101	0.8310
6	3	0.3457	31.75	36.20	1480	31.41	4.45	0.7469	7117	0.8328
7	4	0.3455	31.75	36.20	1470	31.17	4.45	0.7476	7128	0.8345
8	4	0.3455	31.75	36.20	1460	31.03	4.45	0.7459	7111	0.8326
9	5	0.3462	17.60	22.00	1450	30.73	4.40	0.7480	7117	0.8363
10	5	0.3462	17.60	22.00	1470	31.06	4.40	0.7502	7138	0.8388
11	6	0.3455	17.60	22.00	1500	31.82	4.40	0.7473	7124	0.8389
12	6	0.3455	17.60	22.00	1470	31.22	4.40	0.7464	7116	0.8379
13	7	0.3454	90.10	94.40	1330	31.00	4.30	0.6801	6486	0.7728
14	7	0.3454	90.10	94.40	1360	31.60	4.30	0.6822	6506	0.7752
15	8	0.3462	90.10	94.40	1350	31.80	4.30	0.6730	6403	0.7611
16	8	0.3462	90.10	94.40	1350	31.87	4.30	0.6715	6389	0.7595
17	9	0.3448	1.60	-	1140	34.39	4.20	0.5255	5020	0.6063

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1180	35.26	4.20	0.5305	5068	0.6120
19	10	0.3457	1.60	-	970	30.64	4.20	0.5018	4782	0.5760
20	10	0.3457	1.60	-	1040	33.76	4.20	0.4883	4653	0.5605
21	11	0.3464	2.70	6.80	1560	34.20	4.10	0.7231	6876	0.8366
22	11	0.3464	2.70	6.80	1620	35.71	4.10	0.7191	6838	0.8320
23	12	0.3456	2.70	6.80	1450	34.30	4.10	0.6701	6387	0.7789
24	12	0.3456	2.70	6.80	1400	33.02	4.10	0.6721	6406	0.7812
25	13	0.3467	60.00	64.00	1720	37.80	4.00	0.7213	6853	0.8434
26	13	0.3467	60.00	64.00	1670	36.77	4.00	0.7200	6840	0.8418
27	14	0.3445	60.00	64.00	1460	32.24	4.00	0.7179	6864	0.8501
28	14	0.3445	60.00	64.00	1570	34.60	4.00	0.7193	6878	0.8518
29	15	0.3452	29.50	33.60	1280	28.60	4.10	0.7095	6770	0.8265
30	15	0.3452	29.50	33.60	1670	36.81	4.10	0.7192	6863	0.8378
31	16	0.3447	29.50	33.60	1460	32.19	4.10	0.7190	6871	0.8400
32	16	0.3447	29.50	33.60	1630	35.84	4.10	0.7209	6890	0.8423
33	17	0.3455	1.50	5.60	1580	35.17	4.10	0.7121	6790	0.8282
34	17	0.3455	1.50	5.60	1600	35.57	4.10	0.7131	6798	0.8293
35	18	0.3449	1.50	5.60	1530	33.96	4.10	0.7142	6821	0.8335
36	18	0.3449	1.50	5.60	1500	33.53	4.10	0.7092	6773	0.8276
AVERAGE							4.24	0.6973	6692	0.8029
						TOTAL IN GPM	FLOW	12.5516		

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different than the actual head present in the trough. Hence, for calculation purpose net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-4

Run # 7 — **Water Temperature: 73.2 F**
Date: 6/16/93 — **Water Density: 997.562 Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.947 cp**
Experimental Condition: Constant Inlet Flow of Water (16.24 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.75	71.00	1810	29.97	8.25	0.9574	9254	0.7885
2	1	0.3447	62.75	71.00	1890	30.95	8.25	0.9680	9357	0.7973
3	2	0.3458	62.75	71.00	1920	31.63	8.25	0.9622	9272	0.7875
4	2	0.3458	62.75	71.00	1860	30.54	8.25	0.9654	9302	0.7902
5	3	0.3457	31.75	40.00	1850	30.47	8.25	0.9625	9276	0.7882
6	3	0.3457	31.75	40.00	1780	29.49	8.25	0.9568	9222	0.7835
7	4	0.3455	31.75	40.10	1920	31.59	8.35	0.9635	9291	0.7852
8	4	0.3455	31.75	40.10	1900	31.23	8.35	0.9644	9301	0.7859
9	5	0.3462	17.60	25.70	1860	30.41	8.10	0.9696	9331	0.7990
10	5	0.3462	17.60	25.70	1860	30.29	8.10	0.9734	9368	0.8022
11	6	0.3455	17.60	25.70	1900	31.34	8.10	0.9610	9268	0.7952
12	6	0.3455	17.60	25.70	1880	30.90	8.10	0.9645	9301	0.7980
13	7	0.3454	90.10	98.20	1810	32.15	8.10	0.8924	8609	0.7388
14	7	0.3454	90.10	98.20	1730	30.70	8.10	0.8933	8617	0.7395
15	8	0.3462	90.10	98.20	1780	31.85	8.10	0.8859	8526	0.7301
16	8	0.3462	90.10	98.20	1800	32.23	8.10	0.8853	8520	0.7296
17	9	0.3448	1.60	-	1710	34.63	8.05	0.7828	7564	0.6523

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1750	35.54	8.05	0.7806	7543	0.6505
19	10	0.3457	1.60	-	1450	31.27	8.05	0.7351	7085	0.6094
20	10	0.3457	1.60	-	1450	30.99	8.05	0.7417	7149	0.6149
21	11	0.3464	2.70	10.70	1880	31.70	8.00	0.9401	9043	0.7787
22	11	0.3464	2.70	10.70	1890	31.85	8.00	0.9407	9048	0.7791
23	12	0.3456	2.70	10.70	1750	30.75	8.00	0.9021	8697	0.7507
24	12	0.3456	2.70	10.70	1750	30.73	8.00	0.9027	8703	0.7512
25	13	0.3467	60.00	67.80	1830	30.41	7.80	0.9539	9168	0.7988
26	13	0.3467	60.00	67.80	1870	31.04	7.80	0.9550	9178	0.7997
27	14	0.3445	60.00	67.80	1810	30.12	7.80	0.9526	9213	0.8079
28	14	0.3445	60.00	67.80	1910	31.90	7.80	0.9491	9180	0.8049
29	15	0.3452	29.50	37.50	1850	30.95	8.00	0.9475	9146	0.7903
30	15	0.3452	29.50	37.50	1840	30.67	8.00	0.9510	9179	0.7932
31	16	0.3447	29.50	37.50	1890	31.58	8.00	0.9487	9170	0.7935
32	16	0.3447	29.50	37.50	1840	30.86	8.00	0.9452	9136	0.7906
33	17	0.3455	1.50	9.40	1900	32.06	7.90	0.9395	9060	0.7871
34	17	0.3455	1.50	9.40	1850	31.21	7.90	0.9396	9062	0.7873
35	18	0.3449	1.50	9.40	1950	32.87	7.90	0.9404	9085	0.7906
36	18	0.3449	1.50	9.40	1935	32.69	7.90	0.9383	9065	0.7889
AVERAGE							8.06	0.9226	8931	0.7681
						TOTAL IN FLOW GPM		16.6062		

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-5

Run # 8 **Water Temperature: 73.2 F**
Date: 6/18/93 **Water Density: 997.562 Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.947 cp**
Experimental Condition: Constant Inlet Flow of Water (18.10 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	73.50	1930	28.86	10.70	1.0601	10247	0.7667
2	1	0.3447	62.80	73.50	1950	29.04	10.70	1.0644	10289	0.7699
3	2	0.3458	62.80	73.50	1930	28.62	10.70	1.0690	10300	0.7682
4	2	0.3458	62.80	73.50	1960	29.12	10.70	1.0670	10280	0.7668
5	3	0.3457	31.70	42.50	1970	29.24	10.80	1.0680	10294	0.7644
6	3	0.3457	31.70	42.50	1940	28.77	10.80	1.0689	10302	0.7651
7	4	0.3455	31.70	42.50	1980	29.28	10.80	1.0720	10338	0.7681
8	4	0.3455	31.70	42.50	1990	29.63	10.80	1.0646	10267	0.7629
9	5	0.3462	17.60	28.20	1920	28.16	10.60	1.0808	10402	0.7786
10	5	0.3462	17.60	28.20	1900	27.87	10.60	1.0807	10401	0.7785
11	6	0.3455	17.60	28.20	1970	29.20	10.60	1.0695	10314	0.7735
12	6	0.3455	17.60	28.20	1970	29.21	10.60	1.0691	10310	0.7733
13	7	0.3454	90.25	100.70	1860	29.09	10.45	1.0136	9777	0.7388
14	7	0.3454	90.25	100.70	1930	30.31	10.45	1.0094	9737	0.7357
15	8	0.3462	90.25	100.70	1920	29.90	10.45	1.0179	9797	0.7385
16	8	0.3462	90.25	100.70	1940	30.16	10.45	1.0197	9813	0.7398
17	9	0.3448	1.60	-	1870	31.48	10.40	0.9417	9099	0.6904

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM.	LIQUID ELEVATION CM.	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM.	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1930	32.36	10.40	0.9454	9136	0.6932
19	10	0.3457	1.60	-	1530	26.83	10.40	0.9040	8713	0.6593
20	10	0.3457	1.60	-	1620	28.19	10.40	0.9110	8780	0.6644
21	11	0.3464	2.75	13.10	1910	28.52	10.35	1.0616	10211	0.7730
22	11	0.3464	2.75	13.10	1870	27.94	10.35	1.0610	10205	0.7726
23	12	0.3456	2.75	13.10	1900	29.08	10.35	1.0357	9985	0.7577
24	12	0.3456	2.75	13.10	1900	28.99	10.35	1.0389	10016	0.7600
25	13	0.3467	59.90	70.30	1960	29.09	10.40	1.0681	10264	0.7745
26	13	0.3467	59.90	70.30	1930	28.75	10.40	1.0642	10227	0.7717
27	14	0.3445	59.90	70.30	1920	28.62	10.40	1.0634	10285	0.7811
28	14	0.3445	59.90	70.30	1950	29.06	10.40	1.0637	10288	0.7812
29	15	0.3452	29.50	39.90	1980	29.64	10.40	1.0589	10221	0.7746
30	15	0.3452	29.50	39.90	1970	29.36	10.40	1.0636	10266	0.7780
31	16	0.3447	29.50	39.90	1950	29.27	10.40	1.0561	10208	0.7747
32	16	0.3447	29.50	39.90	2000	30.11	10.40	1.0529	10178	0.7724
33	17	0.3455	1.50	11.80	1940	29.54	10.30	1.0411	10040	0.7639
34	17	0.3455	1.50	11.80	1980	29.97	10.30	1.0473	10100	0.7684
35	18	0.3449	1.50	11.80	1980	29.71	10.30	1.0564	10206	0.7779
36	18	0.3449	1.50	11.80	1990	29.94	10.30	1.0536	10178	0.7758
AVERAGE							10.50	1.0412	10065	0.7585
						TOTAL IN GPM	FLOW	18.7416		

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-6

Run # 9 — Water Temperature: 73.0 F
Date: 6/19/93 — Water Density: 997.609 Kg / Cu.m.
Plate Thickness : 11 gage — Water Viscosity: 0.949 cp
Experimental Condition: Constant Inlet Flow of Water (20.02 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	76.10	1950	26.77	13.30	1.1547	11138	0.7491
2	1	0.3447	62.80	76.10	1910	26.02	13.30	1.1636	11224	0.7549
3	2	0.3458	62.80	76.10	1910	25.92	13.30	1.1681	11232	0.7530
4	2	0.3458	62.80	76.10	1970	26.67	13.30	1.1709	11259	0.7548
5	3	0.3457	31.70	45.15	1855	25.20	13.45	1.1669	11223	0.7484
6	3	0.3457	31.70	45.15	1890	25.85	13.45	1.1590	11148	0.7433
7	4	0.3455	31.70	45.15	1940	26.52	13.45	1.1596	11160	0.7446
8	4	0.3455	31.70	45.15	2085	28.69	13.45	1.1520	11087	0.7397
9	5	0.3462	17.60	30.70	1880	25.27	13.10	1.1793	11327	0.7642
10	5	0.3462	17.60	30.70	1870	25.12	13.10	1.1801	11334	0.7647
11	6	0.3455	17.60	30.70	1920	26.14	13.10	1.1643	11205	0.7575
12	6	0.3455	17.60	30.70	1960	26.52	13.10	1.1716	11275	0.7622
13	7	0.3454	90.25	103.20	1820	25.59	12.95	1.1274	10853	0.7382
14	7	0.3454	90.25	103.20	1850	26.09	12.95	1.1240	10821	0.7360
15	8	0.3462	90.25	103.20	1950	27.31	12.95	1.1319	10871	0.7377
16	8	0.3462	90.25	103.20	1980	27.82	12.95	1.1282	10836	0.7353
17	9	0.3448	1.60	-	1850	26.81	12.95	1.0939	10548	0.7187

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1900	27.59	12.95	1.0917	10527	0.7173
19	10	0.3457	1.60	-	1770	25.97	12.95	1.0804	10392	0.7062
20	10	0.3457	1.60	-	1880	27.22	12.95	1.0948	10530	0.7156
21	11	0.3464	2.75	15.70	2000	27.34	12.95	1.1596	11131	0.7549
22	11	0.3464	2.75	15.70	1890	25.87	12.95	1.1581	11116	0.7539
23	12	0.3456	2.75	15.70	1850	25.53	12.95	1.1487	11052	0.7512
24	12	0.3456	2.75	15.70	1890	26.02	12.95	1.1514	11078	0.7530
25	13	0.3467	59.90	72.80	1870	25.64	12.90	1.1561	11088	0.7528
26	13	0.3467	59.90	72.80	1910	26.20	12.90	1.1556	11083	0.7524
27	14	0.3445	59.90	72.80	1910	25.95	12.90	1.1668	11261	0.7694
28	14	0.3445	59.90	72.80	1820	24.82	12.90	1.1624	11219	0.7666
29	15	0.3452	29.50	42.45	1960	26.77	12.95	1.1606	11179	0.7608
30	15	0.3452	29.50	42.45	1880	25.74	12.95	1.1578	11152	0.7590
31	16	0.3447	29.50	42.45	1920	26.45	12.95	1.1507	11100	0.7565
32	16	0.3447	29.50	42.45	1895	26.09	12.95	1.1514	11106	0.7569
33	17	0.3455	1.50	14.30	1960	27.41	12.80	1.1335	10909	0.7461
34	17	0.3455	1.50	14.30	1900	26.37	12.80	1.1422	10992	0.7518
35	18	0.3449	1.50	14.30	1880	26.04	12.80	1.1445	11033	0.7559
36	18	0.3449	1.50	14.30	1890	26.23	12.80	1.1422	11012	0.7544
AVERAGE							13.04	1.1473	11042	0.7482

TOTAL IN FLOW = 20.6520 GPM

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-7

Run # 10 **Water Temperature: 72.2 F**
Date: 6/20/93 **Water Density: 997.702 Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.960 cp**
Experimental Condition: Constant Inlet Flow of Water (22.10 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	79.80	1930	23.83	17.00	1.2839	12244	0.7367
2	1	0.3447	62.80	79.80	1880	23.09	17.00	1.2907	12309	0.7406
3	2	0.3458	62.80	79.80	2110	26.06	17.00	1.2835	12201	0.7318
4	2	0.3458	62.80	79.80	1990	24.56	17.00	1.2844	12210	0.7323
5	3	0.3457	31.70	48.80	1920	23.94	17.10	1.2713	12089	0.7231
6	3	0.3457	31.70	48.80	1910	23.49	17.10	1.2889	12256	0.7332
7	4	0.3455	31.70	48.80	1920	23.62	17.10	1.2886	12260	0.7338
8	4	0.3455	31.70	48.80	1950	24.02	17.10	1.2869	12244	0.7328
9	5	0.3462	17.60	34.40	1910	23.16	16.80	1.3073	12413	0.7481
10	5	0.3462	17.60	34.40	1900	22.99	16.80	1.3101	12439	0.7496
11	6	0.3455	17.60	34.40	1950	23.91	16.80	1.2928	12300	0.7428
12	6	0.3455	17.60	34.40	1920	23.45	16.80	1.2979	12349	0.7457
13	7	0.3454	90.25	107.20	1940	24.08	16.95	1.2771	12154	0.7309
14	7	0.3454	90.25	107.20	1940	24.16	16.95	1.2729	12114	0.7285
15	8	0.3462	90.25	107.20	1960	24.62	16.95	1.2620	11983	0.7189
16	8	0.3462	90.25	107.20	1955	24.55	16.95	1.2623	11986	0.7191
17	9	0.3448	1.60	-	1930	23.63	16.78	1.2947	12344	0.7473

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1930	23.90	16.78	1.2801	12204	0.7389
19	10	0.3457	1.60	-	1910	23.79	16.78	1.2727	12102	0.7308
20	10	0.3457	1.60	-	1780	22.29	16.78	1.2659	12037	0.7269
21	11	0.3464	2.75	19.35	1890	23.21	16.60	1.2908	12250	0.7422
22	11	0.3464	2.75	19.35	1880	22.91	16.60	1.3008	12344	0.7479
23	12	0.3456	2.75	19.35	1640	20.45	16.60	1.2713	12092	0.7343
24	12	0.3456	2.75	19.35	1710	21.35	16.60	1.2696	12076	0.7334
25	13	0.3467	59.90	76.40	1840	22.77	16.50	1.2810	12145	0.7375
26	13	0.3467	59.90	76.40	1860	23.05	16.50	1.2792	12128	0.7364
27	14	0.3445	59.90	76.40	1820	22.43	16.50	1.2863	12273	0.7500
28	14	0.3445	59.90	76.40	1880	23.20	16.50	1.2846	12257	0.7490
29	15	0.3452	29.50	46.10	1960	24.15	16.60	1.2865	12251	0.7449
30	15	0.3452	29.50	46.10	1930	23.74	16.60	1.2887	12272	0.7462
31	16	0.3447	29.50	46.10	1880	23.28	16.60	1.2801	12208	0.7433
32	16	0.3447	29.50	46.10	1910	23.73	16.60	1.2759	12168	0.7409
33	17	0.3455	1.50	17.90	1940	24.23	16.40	1.2692	12076	0.7380
34	17	0.3455	1.50	17.90	1930	24.16	16.40	1.2663	12048	0.7364
35	18	0.3449	1.50	17.90	1950	24.29	16.40	1.2726	12129	0.7426
36	18	0.3449	1.50	17.90	1940	24.28	16.40	1.2666	12072	0.7391
AVERAGE							16.75	1.2818	12195	0.7376

TOTAL IN FLOW = 23.0718 GPM

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-8

Run # 11 — **Water Temperature: 73.5 F**
Date: 6/21/93 — **Water Density: 997.515 Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.943 cp**
Experimental Condition: Constant Inlet Flow of Water (23.50 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	82.20	1820	21.31	19.40	1.3539	13141	0.7272
2	1	0.3447	62.80	82.20	1878	21.99	19.40	1.3538	13141	0.7272
3	2	0.3458	62.80	82.20	1920	22.34	19.40	1.3624	13182	0.7271
4	2	0.3458	62.80	82.20	1920	22.41	19.40	1.3581	13141	0.7249
5	3	0.3457	31.70	51.25	1830	21.25	19.55	1.3651	13212	0.7262
6	3	0.3457	31.70	51.25	1840	21.52	19.55	1.3554	13118	0.7210
7	4	0.3455	31.70	51.25	1885	21.97	19.55	1.3601	13171	0.7244
8	4	0.3455	31.70	51.25	1930	22.67	19.55	1.3496	13069	0.7188
9	5	0.3462	17.60	36.80	1895	21.81	19.20	1.3773	13311	0.7372
10	5	0.3462	17.60	36.80	1905	21.96	19.20	1.3751	13290	0.7360
11	6	0.3455	17.60	36.80	1920	22.38	19.20	1.3600	13170	0.7309
12	6	0.3455	17.60	36.80	1920	22.25	19.20	1.3679	13247	0.7351
13	7	0.3454	90.25	109.55	1780	20.91	19.30	1.3494	13072	0.7237
14	7	0.3454	90.25	109.55	1870	21.99	19.30	1.3480	13058	0.7230
15	8	0.3462	90.25	109.55	1895	22.47	19.30	1.3369	12920	0.7137
16	8	0.3462	90.25	109.55	1850	22.02	19.30	1.3318	12871	0.7110
17	9	0.3448	1.60	-	1750	19.81	19.18	1.4004	13589	0.7560

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1790	20.35	19.18	1.3944	13530	0.7528
19	10	0.3457	1.60	-	1900	21.90	19.18	1.3753	13311	0.7386
20	10	0.3457	1.60	-	1860	21.41	19.18	1.3771	13329	0.7396
21	11	0.3464	2.75	21.80	1810	20.88	19.05	1.3741	13273	0.7375
22	11	0.3464	2.75	21.80	1870	21.61	19.05	1.3717	13250	0.7363
23	12	0.3456	2.75	21.80	1890	22.07	19.05	1.3575	13142	0.7320
24	12	0.3456	2.75	21.80	1880	21.88	19.05	1.3621	13186	0.7344
25	13	0.3467	59.90	78.90	1885	21.87	19.00	1.3663	13186	0.7330
26	13	0.3467	59.90	78.90	1905	22.23	19.00	1.3584	13110	0.7288
27	14	0.3445	59.90	78.90	1900	22.02	19.00	1.3678	13284	0.7432
28	14	0.3445	59.90	78.90	1880	21.77	19.00	1.3689	13295	0.7439
29	15	0.3452	29.50	48.60	1905	22.05	19.10	1.3695	13274	0.7392
30	15	0.3452	29.50	48.60	1920	22.30	19.10	1.3648	13229	0.7367
31	16	0.3447	29.50	48.60	1940	22.63	19.10	1.3589	13191	0.7356
32	16	0.3447	29.50	48.60	1940	22.50	19.10	1.3668	13267	0.7399
33	17	0.3455	1.50	20.40	1940	22.79	18.90	1.3494	13068	0.7309
34	17	0.3455	1.50	20.40	1960	23.06	18.90	1.3474	13048	0.7298
35	18	0.3449	1.50	20.40	1965	23.18	18.90	1.3438	13036	0.7304
36	18	0.3449	1.50	20.40	1895	22.26	18.90	1.3495	13091	0.7335
AVERAGE							19.19	1.3619	13189	0.7322

TOTAL IN FLOW = 24.5145 GPM

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-9

Run # 12 **Water Temperature: 73.3 F**
Date: 6/22/93 **Water Density: 997.538 Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.944 cp**
Experimental Condition: Constant Inlet Flow of Water (23.50 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	82.10	1880	21.80	19.30	1.3671	13256	0.7362
2	1	0.3447	62.80	82.10	1795	20.82	19.30	1.3667	13252	0.7360
3	2	0.3458	62.80	82.10	1940	22.62	19.30	1.3595	13141	0.7275
4	2	0.3458	62.80	82.10	1895	21.99	19.30	1.3661	13204	0.7310
5	3	0.3457	31.70	51.10	1890	21.92	19.40	1.3668	13215	0.7299
6	3	0.3457	31.70	51.10	1870	21.65	19.40	1.3692	13238	0.7312
7	4	0.3455	31.70	51.10	1890	21.93	19.40	1.3662	13217	0.7304
8	4	0.3455	31.70	51.10	1875	21.78	19.40	1.3647	13202	0.7296
9	5	0.3462	17.60	36.70	1915	21.88	19.10	1.3874	13395	0.7446
10	5	0.3462	17.60	36.70	1830	20.91	19.10	1.3873	13394	0.7445
11	6	0.3455	17.60	36.70	1865	21.63	19.10	1.3668	13223	0.7365
12	6	0.3455	17.60	36.70	1830	21.18	19.10	1.3696	13250	0.7380
13	7	0.3454	90.25	109.30	1810	21.17	19.05	1.3553	13115	0.7317
14	7	0.3454	90.25	109.30	1795	21.06	19.05	1.3511	13075	0.7294
15	8	0.3462	90.25	109.30	1895	22.41	19.05	1.3405	12941	0.7203
16	8	0.3462	90.25	109.30	1935	22.91	19.05	1.3389	12926	0.7194
17	9	0.3448	1.60	-	1880	21.46	19.00	1.3887	13462	0.7533

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	1880	21.48	19.00	1.3874	13449	0.7526
19	10	0.3457	1.60	-	1880	21.81	19.00	1.3664	13211	0.7373
20	10	0.3457	1.60	-	1920	22.31	19.00	1.3642	13190	0.7362
21	11	0.3464	2.75	21.70	1870	21.68	18.95	1.3673	13193	0.7358
22	11	0.3464	2.75	21.70	1860	21.52	18.95	1.3701	13220	0.7373
23	12	0.3456	2.75	21.70	1850	21.67	18.95	1.3533	13088	0.7317
24	12	0.3456	2.75	21.70	1930	22.48	18.95	1.3610	13162	0.7358
25	13	0.3467	59.90	78.70	1840	21.56	18.80	1.3529	13042	0.7297
26	13	0.3467	59.90	78.70	1900	22.24	18.80	1.3543	13056	0.7304
27	14	0.3445	59.90	78.70	1950	22.74	18.80	1.3593	13189	0.7426
28	14	0.3445	59.90	78.70	1860	21.75	18.80	1.3556	13152	0.7405
29	15	0.3452	29.50	48.45	1910	22.34	18.95	1.3553	13123	0.7344
30	15	0.3452	29.50	48.45	1920	22.40	18.95	1.3587	13156	0.7363
31	16	0.3447	29.50	48.45	1910	22.27	18.95	1.3596	13183	0.7389
32	16	0.3447	29.50	48.45	1900	22.13	18.95	1.3610	13197	0.7397
33	17	0.3455	1.50	20.40	1945	22.94	18.90	1.3440	13002	0.7280
34	17	0.3455	1.50	20.40	1900	22.46	18.90	1.3410	12973	0.7264
35	18	0.3449	1.50	20.40	1870	22.08	18.90	1.3425	13010	0.7297
36	18	0.3449	1.50	20.40	1930	22.63	18.90	1.3519	13102	0.7349
AVERAGE							19.05	1.3616	13172	0.7347

TOTAL INFLOW = 24.5089 GPM

Note: For hole nos. 9 & 10 the observed head in the glass tube was significantly different from the actual head present in the trough. Hence, for calculation purposes, net head for these holes was taken to be average of net heads for adjacent holes (7-8 & 11-12).

TABLE A7-10

Run # 13 **Water Temperature: 75.7F**
Date: 6/23/93 **Water Density: 997.222 Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.917 cp**
Experimental Condition: Constant Inlet Flow of Water (7.35 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	64.60	1005	30.91	1.80	0.5154	5143	0.9089
2	1	0.3447	62.80	64.60	1025	32.09	1.80	0.5063	5053	0.8929
3	2	0.3458	62.80	64.60	1075	31.72	1.80	0.5372	5344	0.9413
4	2	0.3458	62.80	64.60	1105	32.88	1.80	0.5327	5299	0.9334
5	3	0.3457	31.70	33.50	930	31.04	1.80	0.4749	4726	0.8327
6	3	0.3457	31.70	33.50	955	31.91	1.80	0.4744	4720	0.8317
7	4	0.3455	31.70	33.50	930	32.07	1.80	0.4597	4577	0.8069
8	4	0.3455	31.70	33.50	1015	35.68	1.80	0.4509	4490	0.7915
9	5	0.3462	17.60	19.20	1010	32.39	1.60	0.4943	4911	0.9165
10	5	0.3462	17.60	19.20	1010	32.53	1.60	0.4922	4890	0.9126
11	6	0.3455	17.60	19.20	955	34.84	1.60	0.4345	4326	0.8089
12	6	0.3455	17.60	19.20	865	31.02	1.60	0.4420	4401	0.8229
13	7	0.3454	90.25	91.40	955	31.00	1.15	0.4883	4863	1.0730
14	7	0.3454	90.25	91.40	955	31.40	1.15	0.4821	4801	1.0593
15	8	0.3462	90.25	91.40	640	31.21	1.15	0.3251	3230	0.7109
16	8	0.3462	90.25	91.40	630	31.04	1.15	0.3217	3197	0.7037
17	9	0.3448	1.60	-	275	43.99	-	0.0991	989	-

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	320	54.01	-	0.0939	937	-
19	10	0.3457	1.60	-	170	39.55	-	0.0681	678	-
20	10	0.3457	1.60	-	145	37.30	-	0.0616	613	-
21	11	0.3464	2.75	4.10	945	30.84	1.35	0.4857	4823	0.9794
22	11	0.3464	2.75	4.10	940	30.92	1.35	0.4819	4785	0.9717
23	12	0.3456	2.75	4.10	920	35.70	1.35	0.4085	4066	0.8275
24	12	0.3456	2.75	4.10	805	31.29	1.35	0.4078	4059	0.8261
25	13	0.3467	59.90	61.40	960	31.73	1.50	0.4796	4758	0.9158
26	13	0.3467	59.90	61.40	970	32.09	1.50	0.4792	4754	0.9149
27	14	0.3445	59.90	61.40	975	34.27	1.50	0.4510	4503	0.8722
28	14	0.3445	59.90	61.40	945	32.62	1.50	0.4592	4585	0.8881
29	15	0.3452	29.50	31.10	980	33.25	1.60	0.4672	4656	0.8713
30	15	0.3452	29.50	31.10	970	32.56	1.60	0.4722	4706	0.8807
31	16	0.3447	29.50	31.10	950	32.92	1.60	0.4575	4565	0.8556
32	16	0.3447	29.50	31.10	915	31.46	1.60	0.4610	4601	0.8623
33	17	0.3455	1.50	3.00	970	32.35	1.50	0.4753	4732	0.9139
34	17	0.3455	1.50	3.00	985	33.24	1.50	0.4697	4677	0.9032
35	18	0.3449	1.50	3.00	965	33.52	1.50	0.4564	4551	0.8805
36	18	0.3449	1.50	3.00	940	31.33	1.50	0.4756	4743	0.9177
AVERAGE							1.54	0.4206	4188	0.8821

TOTAL INFLOW = 7.5714 GPM

Note: No head developed over holes 9 & 10 because of the splashing effect of the inlet stream.

TABLE A7-11

Run # 14 **Water Temperature: 74.3 F**
Date: 6/25/93 **Water Density: 997.419 Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.932 cp**
Experimental Condition: Constant Inlet Flow of Water (5.65 gpm on Flow Meter)
Inlet at 8.54 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	63.80	865	30.93	1.00	0.4433	4354	1.0488
2	1	0.3447	62.80	63.80	880	31.62	1.00	0.4412	4332	1.0437
3	2	0.3458	62.80	63.80	850	28.47	1.00	0.4733	4633	1.1126
4	2	0.3458	62.80	63.80	910	30.18	1.00	0.4780	4679	1.1236
5	3	0.3457	31.70	32.65	740	30.16	0.95	0.3889	3808	0.9386
6	3	0.3457	31.70	32.65	750	30.74	0.95	0.3868	3787	0.9333
7	4	0.3455	31.70	32.65	680	31.49	0.95	0.3423	3354	0.8270
8	4	0.3455	31.70	32.65	670	30.84	0.95	0.3444	3374	0.8320
9	5	0.3462	17.90	18.60	825	31.34	0.70	0.4173	4080	1.1698
10	5	0.3462	17.90	18.60	825	31.34	0.70	0.4173	4080	1.1698
11	6	0.3455	17.90	18.60	640	31.76	0.70	0.3194	3130	0.8991
12	6	0.3455	17.90	18.60	670	33.58	0.70	0.3163	3099	0.8902
13	7	0.3454	90.25	90.80	660	31.36	0.55	0.3336	3270	1.0600
14	7	0.3454	90.25	90.80	710	31.90	0.55	0.3528	3458	1.1210
15	8	0.3462	90.25	90.80	255	31.30	0.55	0.1291	1263	0.4084
16	8	0.3462	90.25	90.80	255	31.73	0.55	0.1274	1246	0.4029
17	9	0.3448	1.60	-	160	34.19	-	0.0742	728	-

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.60	-	165	34.57	-	0.0757	743	-
19	10	0.3457	1.60	-	170	40.74	-	0.0661	648	-
20	10	0.3457	1.60	-	145	37.74	-	0.0609	596	-
21	11	0.3464	2.75	3.10	590	31.93	0.35	0.2929	2862	1.1599
22	11	0.3464	2.75	3.10	570	31.33	0.35	0.2884	2818	1.1420
23	12	0.3456	2.75	3.10	295	32.03	0.35	0.1460	1430	0.5808
24	12	0.3456	2.75	3.10	305	31.82	0.35	0.1519	1488	0.6045
25	13	0.3467	59.90	60.80	780	31.77	0.90	0.3892	3800	0.9594
26	13	0.3467	59.90	60.80	900	36.11	0.90	0.3951	3858	0.9739
27	14	0.3445	59.90	60.80	630	28.81	0.90	0.3466	3406	0.8655
28	14	0.3445	59.90	60.80	570	26.80	0.90	0.3372	3313	0.8418
29	15	0.3452	29.50	30.50	820	31.88	1.00	0.4077	3998	0.9618
30	15	0.3452	29.50	30.50	810	31.67	1.00	0.4054	3976	0.9564
31	16	0.3447	29.50	30.50	760	32.38	1.00	0.3721	3654	0.8802
32	16	0.3447	29.50	30.50	745	31.84	1.00	0.3709	3642	0.8775
33	17	0.3455	1.50	2.40	900	35.59	0.90	0.4009	3927	0.9950
34	17	0.3455	1.50	2.40	875	34.94	0.90	0.3970	3889	0.9854
35	18	0.3449	1.50	2.40	860	33.74	0.90	0.4041	3966	1.0064
36	18	0.3449	1.50	2.40	910	36.10	0.90	0.3996	3922	0.9953
AVERAGE							0.79	0.3193	3128	0.9302

TOTAL INFLOW = 5.7466 GPM

Note: No head developed over holes 9 & 10 because of the splashing effect of the inlet stream.

TABLE A7-12

Run # 15 — **Water Temperature: 76.0 F**
Date: 6/28/93 — **Water Density: 997.197Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.932 cp**
Experimental Condition: Constant Inlet Flow of Water (5.92 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	63.90	885	32.93	1.10	0.4260	4274	0.9610
2	1	0.3447	62.80	63.90	850	31.56	1.10	0.4269	4284	0.9630
3	2	0.3458	62.80	63.90	850	32.43	1.10	0.4155	4155	0.9313
4	2	0.3458	62.80	63.90	865	32.84	1.10	0.4175	4176	0.9359
5	3	0.3457	31.60	32.90	840	32.05	1.30	0.4155	4156	0.8571
6	3	0.3457	31.60	32.90	840	32.21	1.30	0.4134	4136	0.8528
7	4	0.3455	31.60	32.90	805	32.74	1.30	0.3898	3902	0.8050
8	4	0.3455	31.60	32.90	805	32.64	1.30	0.3910	3914	0.8075
9	5	0.3462	17.50	18.30	830	37.53	0.80	0.3506	3502	0.9193
10	5	0.3462	17.50	18.30	830	37.61	0.80	0.3498	3495	0.9173
11	6	0.3455	17.50	18.30	740	34.54	0.80	0.3396	3400	0.8942
12	6	0.3455	17.50	18.30	730	34.05	0.80	0.3399	3402	0.8948
13	7	0.3454	90.20	90.25	370	36.57	0.05	0.1604	1606	1.6900
14	7	0.3454	90.20	90.25	380	37.39	0.05	0.1611	1613	1.6976
15	8	0.3462	90.20	90.25	450	37.47	0.05	0.1904	1902	1.9968
16	8	0.3462	90.20	90.25	480	34.68	0.05	0.2194	2192	2.3013
17	9	0.3448	1.40	1.60	475	40.27	0.20	0.1870	1875	0.9886

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.40	1.60	475	40.10	0.20	0.1878	1883	0.9928
19	10	0.3457	1.40	1.60	285	38.49	0.20	0.1174	1174	0.6173
20	10	0.3457	1.40	1.60	325	37.24	0.20	0.1383	1384	0.7276
21	11	0.3464	2.70	3.70	825	32.34	1.00	0.4044	4037	0.9473
22	11	0.3464	2.70	3.70	895	34.67	1.00	0.4092	4086	0.9586
23	12	0.3456	2.70	3.70	815	32.78	1.00	0.3941	3944	0.9276
24	12	0.3456	2.70	3.70	855	36.66	1.00	0.3697	3700	0.8701
25	13	0.3467	59.70	60.75	935	38.06	1.05	0.3894	3885	0.8888
26	13	0.3467	59.70	60.75	890	36.79	1.05	0.3835	3825	0.8752
27	14	0.3445	59.70	60.75	915	39.41	1.05	0.3680	3695	0.8507
28	14	0.3445	59.70	60.75	795	33.95	1.05	0.3712	3727	0.8580
29	15	0.3452	29.40	30.35	805	33.02	0.95	0.3865	3872	0.9353
30	15	0.3452	29.40	30.35	950	38.91	0.95	0.3870	3878	0.9367
31	16	0.3447	29.40	30.35	860	36.65	0.95	0.3720	3732	0.9029
32	16	0.3447	29.40	30.35	910	38.90	0.95	0.3708	3721	0.9001
33	17	0.3455	1.40	2.25	900	38.15	0.85	0.3740	3743	0.9552
34	17	0.3455	1.40	2.25	915	38.53	0.85	0.3764	3768	0.9615
35	18	0.3449	1.40	2.25	875	38.49	0.85	0.3604	3614	0.9237
36	18	0.3449	1.40	2.25	960	42.02	0.85	0.3622	3632	0.9282
AVERAGE							0.81	0.3366	3369	1.0103

TOTAL INFLOW = 6.0580 GPM

Note: Negligible head developed over holes 7 & 8 because of the splashing effect of the inlet stream. Hence abnormal coefficients were obtained.

TABLE A7-13

Run # 16 — **Water Temperature: 75.0 F**

Date: 6/29/93 — **Water Density: 997.321Kg / Cu.m.**

Plate Thickness : 11 gage — **Water Viscosity: 0.924 cp**

Experimental Condition: Constant Inlet Flow of Water (8.06 gpm on Flow Meter)

Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.60	64.60	965	29.85	2.00	0.5125	5076	0.8573
2	1	0.3447	62.60	64.60	985	30.31	2.00	0.5152	5102	0.8618
3	2	0.3458	62.60	64.60	975	30.41	2.00	0.5082	5018	0.8448
4	2	0.3458	62.60	64.60	965	30.27	2.00	0.5054	4989	0.8400
5	3	0.3457	31.70	33.50	960	30.27	1.80	0.5027	4965	0.8814
6	3	0.3457	31.70	33.50	955	30.16	1.80	0.5019	4957	0.8800
7	4	0.3455	31.70	33.50	970	30.78	1.80	0.4996	4936	0.8768
8	4	0.3455	31.70	33.50	880	27.97	1.80	0.4987	4928	0.8754
9	5	0.3462	17.40	19.35	965	30.59	1.95	0.5001	4931	0.8399
10	5	0.3462	17.40	19.35	985	31.10	1.95	0.5021	4951	0.8432
11	6	0.3455	17.40	19.35	950	30.44	1.95	0.4947	4889	0.8343
12	6	0.3455	17.40	19.35	955	30.42	1.95	0.4977	4917	0.8392
13	7	0.3454	90.05	91.60	950	31.06	1.55	0.4848	4792	0.9176
14	7	0.3454	90.05	91.60	930	30.81	1.55	0.4785	4730	0.9056
15	8	0.3462	90.05	91.60	915	31.12	1.55	0.4661	4596	0.8780
16	8	0.3462	90.05	91.60	945	31.97	1.55	0.4686	4621	0.8827
17	9	0.3448	1.25	1.80	510	32.77	0.55	0.2467	2443	0.7865

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.25	1.80	540	33.33	0.55	0.2568	2543	0.8188
19	10	0.3457	1.25	1.80	600	33.32	0.55	0.2855	2819	0.9053
20	10	0.3457	1.25	1.80	620	33.53	0.55	0.2931	2895	0.9297
21	11	0.3464	2.60	4.30	940	31.59	1.70	0.4717	4649	0.8475
22	11	0.3464	2.60	4.30	970	32.64	1.70	0.4711	4643	0.8464
23	12	0.3456	2.60	4.30	885	29.42	1.70	0.4769	4711	0.8607
24	12	0.3456	2.60	4.30	895	30.36	1.70	0.4673	4616	0.8435
25	13	0.3467	59.60	61.40	945	32.27	1.80	0.4642	4571	0.8092
26	13	0.3467	59.60	61.40	945	32.71	1.80	0.4580	4510	0.7983
27	14	0.3445	59.60	61.40	935	32.46	1.80	0.4566	4525	0.8061
28	14	0.3445	59.60	61.40	950	33.55	1.80	0.4489	4448	0.7924
29	15	0.3452	29.40	31.00	940	32.81	1.60	0.4542	4492	0.8470
30	15	0.3452	29.40	31.00	950	32.81	1.60	0.4590	4539	0.8560
31	16	0.3447	29.40	31.00	890	31.84	1.60	0.4431	4389	0.8287
32	16	0.3447	29.40	31.00	890	31.84	1.60	0.4431	4389	0.8287
33	17	0.3455	1.45	3.00	910	30.83	1.55	0.4679	4623	0.8850
34	17	0.3455	1.45	3.00	955	31.91	1.55	0.4744	4688	0.8973
35	18	0.3449	1.45	3.00	890	30.66	1.55	0.4602	4555	0.8734
36	18	0.3449	1.45	3.00	960	32.82	1.55	0.4637	4590	0.8801
AVERAGE							1.61	0.4555	4501	0.8555

TOTAL INFLOW = 8.1995 (GPM)

Note: Lower head was observed over holes 9 & 10 because of the splashing effect of the inlet stream.

TABLE A7-14

Run # 17 **Water Temperature: 77.0 F**
Date: 6/30/93 **Water Density: 997.045Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.900 cp**
Experimental Condition: Constant Inlet Flow of Water (10.00 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.60	65.70	1770	45.15	3.10	0.6214	6317	0.8350
2	1	0.3447	62.60	65.70	1780	45.33	3.10	0.6225	6328	0.8364
3	2	0.3458	62.60	65.70	1370	35.04	3.10	0.6198	6280	0.8275
4	2	0.3458	62.60	65.70	1390	35.65	3.10	0.6181	6263	0.8252
5	3	0.3457	31.70	34.70	1375	35.35	3.00	0.6166	6250	0.8373
6	3	0.3457	31.70	34.70	1390	35.70	3.00	0.6172	6256	0.8382
7	4	0.3455	31.70	34.70	1365	35.27	3.00	0.6135	6222	0.8341
8	4	0.3455	31.70	34.70	1370	35.48	3.00	0.6121	6208	0.8322
9	5	0.3462	17.40	20.35	1455	37.70	2.95	0.6118	6192	0.8354
10	5	0.3462	17.40	20.35	1450	37.54	2.95	0.6123	6197	0.8361
11	6	0.3455	17.40	20.35	1375	35.87	2.95	0.6077	6163	0.8331
12	6	0.3455	17.40	20.35	1385	36.00	2.95	0.6099	6185	0.8362
13	7	0.3454	90.05	92.65	1235	35.57	2.60	0.5504	5584	0.8043
14	7	0.3454	90.05	92.65	1255	36.11	2.60	0.5509	5589	0.8051
15	8	0.3462	90.05	92.65	1275	34.22	2.60	0.5906	5978	0.8591
16	8	0.3462	90.05	92.65	1330	35.35	2.60	0.5964	6037	0.8675
17	9	0.3448	1.25	3.60	935	37.52	2.35	0.3950	4015	0.6093

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.25	3.60	985	38.92	2.35	0.4012	4077	0.6188
19	10	0.3457	1.25	3.60	770	31.34	2.35	0.3895	3948	0.5976
20	10	0.3457	1.25	3.60	900	36.51	2.35	0.3908	3961	0.5996
21	11	0.3464	2.60	5.30	1270	33.76	2.70	0.5963	6032	0.8502
22	11	0.3464	2.60	5.30	1320	35.28	2.70	0.5931	6000	0.8456
23	12	0.3456	2.60	5.30	1150	30.88	2.70	0.5903	5986	0.8455
24	12	0.3456	2.60	5.30	1200	32.20	2.70	0.5908	5990	0.8461
25	13	0.3467	59.60	62.40	1740	47.44	2.80	0.5814	5876	0.8126
26	13	0.3467	59.60	62.40	1180	31.86	2.80	0.5871	5934	0.8205
27	14	0.3445	59.60	62.40	1120	30.55	2.80	0.5812	5911	0.8226
28	14	0.3445	59.60	62.40	1130	31.00	2.80	0.5778	5877	0.8179
29	15	0.3452	29.40	32.00	1120	30.55	2.60	0.5812	5899	0.8502
30	15	0.3452	29.40	32.00	1500	40.76	2.60	0.5834	5922	0.8534
31	16	0.3447	29.40	32.00	1100	30.51	2.60	0.5715	5810	0.8385
32	16	0.3447	29.40	32.00	1120	30.90	2.60	0.5746	5841	0.8430
33	17	0.3455	1.45	3.90	1280	35.46	2.45	0.5722	5803	0.8609
34	17	0.3455	1.45	3.90	1120	30.85	2.45	0.5755	5837	0.8658
35	18	0.3449	1.45	3.90	1090	30.47	2.45	0.5671	5761	0.8561
36	18	0.3449	1.45	3.90	1090	30.50	2.45	0.5665	5756	0.8553
AVERAGE							2.73	0.5705	5786	0.8126

TOTAL INFLOW = 10.2688 (GPM)

TABLE A7-15

Run # 18 **Water Temperature: 76.0 F**
Date: 7/2/93 **Water Density: 997.045Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.912 cp**
Experimental Condition: Constant Inlet Flow of Water (12.01 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	66.70	1680	37.12	3.90	0.7174	7198	0.8595
2	1	0.3447	62.80	66.70	1690	37.38	3.90	0.7167	7191	0.8586
3	2	0.3458	62.80	66.70	1370	30.03	3.90	0.7232	7233	0.8609
4	2	0.3458	62.80	66.70	1375	30.13	3.90	0.7234	7235	0.8611
5	3	0.3457	31.75	35.80	1560	34.33	4.05	0.7203	7206	0.8419
6	3	0.3457	31.75	35.80	1570	34.46	4.05	0.7222	7225	0.8441
7	4	0.3455	31.75	35.80	1440	32.01	4.05	0.7131	7138	0.8344
8	4	0.3455	31.75	35.80	1375	30.43	4.05	0.7163	7170	0.8382
9	5	0.3462	17.50	21.50	1360	30.02	4.00	0.7181	7174	0.8421
10	5	0.3462	17.50	21.50	1385	30.63	4.00	0.7168	7161	0.8406
11	6	0.3455	17.50	21.50	1620	36.63	4.00	0.7011	7018	0.8255
12	6	0.3455	17.50	21.50	1465	33.01	4.00	0.7035	7042	0.8283
13	7	0.3454	90.05	94.00	1550	35.86	3.95	0.6852	6861	0.8123
14	7	0.3454	90.05	94.00	1695	39.11	3.95	0.6870	6879	0.8145
15	8	0.3462	90.05	94.00	1275	30.70	3.95	0.6583	6577	0.7769
16	8	0.3462	90.05	94.00	1280	30.75	3.95	0.6599	6592	0.7787
17	9	0.3448	1.40	6.40	1330	34.49	3.88	0.6113	6131	0.7338

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.40	6.40	1520	39.21	3.88	0.6145	6164	0.7376
19	10	0.3457	1.40	6.40	1220	32.07	3.88	0.6030	6033	0.7201
20	10	0.3457	1.40	6.40	1210	31.67	3.88	0.6056	6059	0.7232
21	11	0.3464	2.70	6.50	1365	31.16	3.80	0.6944	6933	0.8345
22	11	0.3464	2.70	6.50	1425	32.49	3.80	0.6953	6942	0.8355
23	12	0.3456	2.70	6.50	1370	31.33	3.80	0.6932	6937	0.8369
24	12	0.3456	2.70	6.50	1360	31.43	3.80	0.6859	6864	0.8281
25	13	0.3467	59.70	63.60	1730	39.22	3.90	0.6992	6975	0.8280
26	13	0.3467	59.70	63.60	1400	31.76	3.90	0.6988	6971	0.8275
27	14	0.3445	59.70	63.60	1460	33.53	3.90	0.6902	6929	0.8279
28	14	0.3445	59.70	63.60	1360	30.88	3.90	0.6981	7009	0.8373
29	15	0.3452	29.40	33.20	1360	30.93	3.80	0.6970	6983	0.8435
30	15	0.3452	29.40	33.20	1630	37.16	3.80	0.6953	6966	0.8414
31	16	0.3447	29.40	33.20	1380	31.75	3.80	0.6890	6913	0.8362
32	16	0.3447	29.40	33.20	1430	33.13	3.80	0.6842	6865	0.8304
33	17	0.3455	1.40	5.20	1340	30.86	3.80	0.6883	6890	0.8315
34	17	0.3455	1.40	5.20	1340	31.07	3.80	0.6837	6844	0.8259
35	18	0.3449	1.40	5.20	1320	30.99	3.80	0.6752	6771	0.8185
36	18	0.3449	1.40	5.20	1380	32.44	3.80	0.6743	6762	0.8175
AVERAGE							3.90	0.6878	6884	0.8204

TOTAL INFLOW = 12.3797 (GPM)

Note: For holes no. 9 & 10 the head measured was different from the actual head.
Thus, average of net heads over holes 7-8 and 11-12 was used for calculation of orfice coefficient for 9-10.

TABLE A7-16

Run # 19 **Water Temperature: 77.3 F**
Date: 7/3/93 **Water Density: 996.993Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.897 cp**
Experimental Condition: Constant Inlet Flow of Water (14.05 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	68.60	1790	33.67	5.80	0.8427	8455	0.8279
2	1	0.3447	62.80	68.60	1640	31.11	5.80	0.8357	8384	0.8209
3	2	0.3458	62.80	68.60	1620	30.81	5.80	0.8335	8336	0.8136
4	2	0.3458	62.80	68.60	1700	32.34	5.80	0.8333	8334	0.8134
5	3	0.3457	31.75	37.60	1680	31.84	5.85	0.8364	8368	0.8134
6	3	0.3457	31.75	37.60	1745	33.01	5.85	0.8380	8383	0.8149
7	4	0.3455	31.75	37.60	1690	32.16	5.85	0.8330	8339	0.8110
8	4	0.3455	31.75	37.60	1610	30.62	5.85	0.8335	8343	0.8115
9	5	0.3462	17.50	23.40	1730	32.91	5.90	0.8333	8325	0.8046
10	5	0.3462	17.50	23.40	1750	33.23	5.90	0.8348	8340	0.8061
11	6	0.3455	17.50	23.40	1820	34.95	5.90	0.8255	8263	0.8003
12	6	0.3455	17.50	23.40	1720	33.09	5.90	0.8240	8248	0.7988
13	7	0.3454	90.05	95.80	1540	31.02	5.75	0.7870	7880	0.7733
14	7	0.3454	90.05	95.80	1600	32.50	5.75	0.7804	7814	0.7668
15	8	0.3462	90.05	95.80	1800	37.26	5.75	0.7658	7650	0.7490
16	8	0.3462	90.05	95.80	1770	36.77	5.75	0.7631	7623	0.7463
17	9	0.3448	1.40	8.80	1500	32.45	5.68	0.7328	7350	0.7270

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.40	8.80	1580	34.16	5.68	0.7332	7354	0.7274
19	10	0.3457	1.40	8.80	1410	31.02	5.68	0.7205	7209	0.7111
20	10	0.3457	1.40	8.80	1390	30.80	5.68	0.7154	7157	0.7061
21	11	0.3464	2.70	8.30	1610	31.27	5.60	0.8162	8149	0.8080
22	11	0.3464	2.70	8.30	1850	35.77	5.60	0.8199	8186	0.8116
23	12	0.3456	2.70	8.30	1590	31.24	5.60	0.8068	8074	0.8024
24	12	0.3456	2.70	8.30	1640	32.52	5.60	0.7994	8000	0.7951
25	13	0.3467	59.70	65.40	1640	31.81	5.70	0.8173	8153	0.8005
26	13	0.3467	59.70	65.40	1740	33.76	5.70	0.8170	8150	0.8003
27	14	0.3445	59.70	65.40	1690	32.81	5.70	0.8165	8197	0.8100
28	14	0.3445	59.70	65.40	1670	32.43	5.70	0.8163	8195	0.8098
29	15	0.3452	29.40	35.00	1690	32.81	5.60	0.8165	8181	0.8139
30	15	0.3452	29.40	35.00	1720	33.28	5.60	0.8193	8208	0.8167
31	16	0.3447	29.40	35.00	1590	31.19	5.60	0.8081	8108	0.8079
32	16	0.3447	29.40	35.00	1570	30.80	5.60	0.8080	8107	0.8078
33	17	0.3455	1.40	6.95	1580	31.03	5.55	0.8072	8080	0.8068
34	17	0.3455	1.40	6.95	1740	34.28	5.55	0.8046	8054	0.8043
35	18	0.3449	1.40	6.95	1720	33.95	5.55	0.8031	8053	0.8056
36	18	0.3449	1.40	6.95	1660	32.63	5.55	0.8064	8087	0.8089
AVERAGE							5.71	0.8051	8059	0.7931

TOTAL INFLOW = 14.4922
(GPM)

Note: For holes 9-10 the net head is average of the neighboring holes (7-8 & 11-12).
The liquid elevation column reads the head shown in the glass tubes which was different from what was actually present.

TABLE A7-17

Run # 20 **Water Temperature: 77.5 F**
Date: 7/3/93 **Water Density: 996.967Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.895 cp**
Experimental Condition: Constant Inlet Flow of Water (16.00 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	70.70	1835	30.75	7.90	0.9460	9491	0.7962
2	1	0.3447	62.80	70.70	1820	30.49	7.90	0.9462	9494	0.7965
3	2	0.3458	62.80	70.70	1825	30.61	7.90	0.9451	9452	0.7905
4	2	0.3458	62.80	70.70	1825	30.67	7.90	0.9433	9434	0.7889
5	3	0.3457	31.75	39.60	1830	30.82	7.85	0.9412	9417	0.7902
6	3	0.3457	31.75	39.60	1835	30.89	7.85	0.9417	9421	0.7906
7	4	0.3455	31.75	39.60	1855	31.11	7.85	0.9452	9462	0.7944
8	4	0.3455	31.75	39.60	1900	31.89	7.85	0.9445	9454	0.7938
9	5	0.3462	17.50	25.40	1840	30.82	7.90	0.9464	9454	0.7897
10	5	0.3462	17.50	25.40	1855	31.02	7.90	0.9480	9470	0.7910
11	6	0.3455	17.50	25.40	1820	30.91	7.90	0.9334	9343	0.7820
12	6	0.3455	17.50	25.40	1830	30.95	7.90	0.9373	9382	0.7853
13	7	0.3454	90.05	97.90	1835	30.83	7.85	0.9435	9447	0.7935
14	7	0.3454	90.05	97.90	1840	30.92	7.85	0.9433	9446	0.7933
15	8	0.3462	90.05	97.90	1675	30.22	7.85	0.8786	8777	0.7355
16	8	0.3462	90.05	97.90	1675	30.49	7.85	0.8708	8700	0.7290
17	9	0.3448	1.40	11.05	1685	31.74	7.73	0.8415	8441	0.7157

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.40	11.05	1675	31.66	7.73	0.8387	8412	0.7132
19	10	0.3457	1.40	11.05	1630	31.38	7.73	0.8234	8238	0.6966
20	10	0.3457	1.40	11.05	1600	30.66	7.73	0.8272	8276	0.6998
21	11	0.3464	2.70	10.30	1810	30.80	7.60	0.9316	9301	0.7916
22	11	0.3464	2.70	10.30	1810	30.66	7.60	0.9358	9343	0.7952
23	12	0.3456	2.70	10.30	1770	30.38	7.60	0.9236	9242	0.7885
24	12	0.3456	2.70	10.30	1790	30.65	7.60	0.9258	9264	0.7903
25	13	0.3467	59.70	67.40	1790	30.68	7.70	0.9249	9226	0.7795
26	13	0.3467	59.70	67.40	1660	28.38	7.70	0.9272	9249	0.7814
27	14	0.3445	59.70	67.40	1830	31.34	7.70	0.9256	9293	0.7901
28	14	0.3445	59.70	67.40	1800	30.64	7.70	0.9313	9349	0.7949
29	15	0.3452	29.40	36.80	1800	30.70	7.40	0.9294	9312	0.8060
30	15	0.3452	29.40	36.80	1810	30.75	7.40	0.9331	9348	0.8091
31	16	0.3447	29.40	36.80	1680	28.78	7.40	0.9253	9284	0.8048
32	16	0.3447	29.40	36.80	1770	30.06	7.40	0.9334	9365	0.8118
33	17	0.3455	1.40	8.80	1760	30.53	7.40	0.9138	9148	0.7911
34	17	0.3455	1.40	8.80	1660	28.71	7.40	0.9166	9175	0.7934
35	18	0.3449	1.40	8.80	1780	30.77	7.40	0.9170	9195	0.7966
36	18	0.3449	1.40	8.80	1800	30.93	7.40	0.9225	9251	0.8014
AVERAGE							7.70	0.9195	9204	0.7803
						TOTAL INFLOW (GPM)	=	16.5511		

Note: For holes 9-10 the net head is average of the neighboring holes (7-8 & 11-12).
The liquid elevation column reads the head shown in the glass tubes which was different from what was actually present.

TABLE A7-18

Run # 21 **Water Temperature: 75.5 F**
Date: 7/5/93 **Water Density: 997.247Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.918 cp**
Experimental Condition: Constant Inlet Flow of Water (18.40 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.80	73.20	1930	29.31	10.40	1.0438	10405	0.7658
2	1	0.3447	62.80	73.20	1985	30.11	10.40	1.0450	10417	0.7666
3	2	0.3458	62.80	73.20	1945	29.56	10.40	1.0430	10364	0.7603
4	2	0.3458	62.80	73.20	1920	29.20	10.40	1.0423	10357	0.7598
5	3	0.3457	31.75	42.20	1970	29.70	10.45	1.0515	10451	0.7651
6	3	0.3457	31.75	42.20	1935	29.12	10.45	1.0534	10470	0.7664
7	4	0.3455	31.75	42.20	1940	29.23	10.45	1.0521	10463	0.7664
8	4	0.3455	31.75	42.20	1970	29.52	10.45	1.0579	10521	0.7706
9	5	0.3462	17.50	27.80	1955	29.26	10.30	1.0591	10512	0.7740
10	5	0.3462	17.50	27.80	1960	29.37	10.30	1.0579	10500	0.7731
11	6	0.3455	17.50	27.80	1950	29.73	10.30	1.0397	10340	0.7629
12	6	0.3455	17.50	27.80	1920	29.18	10.30	1.0430	10373	0.7653
13	7	0.3454	90.05	100.40	1905	30.02	10.35	1.0059	10007	0.7367
14	7	0.3454	90.05	100.40	1900	29.88	10.35	1.0080	10028	0.7382
15	8	0.3462	90.05	100.40	1945	31.14	10.35	0.9901	9827	0.7218
16	8	0.3462	90.05	100.40	1920	30.77	10.35	0.9891	9817	0.7211
17	9	0.3448	1.40	14.15	1970	32.79	10.23	0.9524	9491	0.7040

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.40	14.15	1920	31.99	10.23	0.9514	9481	0.7033
19	10	0.3457	1.40	14.15	1885	31.74	10.23	0.9414	9357	0.6923
20	10	0.3457	1.40	14.15	1865	31.31	10.23	0.9442	9385	0.6944
21	11	0.3464	2.70	12.80	1740	26.38	10.10	1.0456	10371	0.7707
22	11	0.3464	2.70	12.80	1740	26.41	10.10	1.0444	10360	0.7699
23	12	0.3456	2.70	12.80	2000	30.56	10.10	1.0374	10314	0.7683
24	12	0.3456	2.70	12.80	1790	27.30	10.10	1.0394	10334	0.7697
25	13	0.3467	59.70	69.80	1920	29.53	10.10	1.0307	10215	0.7584
26	13	0.3467	59.70	69.80	1910	29.24	10.10	1.0355	10262	0.7620
27	14	0.3445	59.70	69.80	1880	28.60	10.10	1.0420	10393	0.7766
28	14	0.3445	59.70	69.80	1840	28.16	10.10	1.0358	10331	0.7720
29	15	0.3452	29.40	39.20	1850	28.59	9.80	1.0258	10210	0.7729
30	15	0.3452	29.40	39.20	1945	29.91	9.80	1.0308	10261	0.7768
31	16	0.3447	29.40	39.20	1860	29.02	9.80	1.0160	10128	0.7678
32	16	0.3447	29.40	39.20	1895	29.27	9.80	1.0263	10230	0.7756
33	17	0.3455	1.40	10.95	1925	30.26	9.55	1.0084	10029	0.7684
34	17	0.3455	1.40	10.95	1910	29.93	9.55	1.0116	10061	0.7709
35	18	0.3449	1.40	10.95	1915	29.93	9.55	1.0143	10104	0.7756
36	18	0.3449	1.40	10.95	1910	29.72	9.55	1.0188	10149	0.7790
AVERAGE							10.14	1.0232	10176	0.7567

TOTAL INFLOW - 18.4171
(GPM)

Note: For holes 9-10 the net head is average of the neighboring holes (7-8 & 11-12).
The liquid elevation column reads the head shown in the glass tubes which was different from what was actually present .

TABLE A7-19

Run # 22 — **Water Temperature: 75.2 F**
Date: 7/6/93 — **Water Density: 997.296Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.922 cp**
Experimental Condition: Constant Inlet Flow of Water (20.67 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.90	75.90	1925	26.56	13.00	1.1489	11404	0.7539
2	1	0.3447	62.90	75.90	1940	26.68	13.00	1.1527	11441	0.7563
3	2	0.3458	62.90	75.90	1915	26.26	13.00	1.1560	11437	0.7537
4	2	0.3458	62.90	75.90	1950	26.87	13.00	1.1504	11382	0.7501
5	3	0.3457	31.80	44.90	1950	26.59	13.10	1.1625	11505	0.7555
6	3	0.3457	31.80	44.90	2015	27.36	13.10	1.1675	11554	0.7587
7	4	0.3455	31.80	44.90	1980	27.08	13.10	1.1590	11477	0.7541
8	4	0.3455	31.80	44.90	1935	26.38	13.10	1.1628	11514	0.7565
9	5	0.3462	17.60	30.75	1900	25.66	13.15	1.1738	11600	0.7591
10	5	0.3462	17.60	30.75	1900	25.55	13.15	1.1788	11650	0.7624
11	6	0.3455	17.60	30.75	1865	25.49	13.15	1.1598	11485	0.7532
12	6	0.3455	17.60	30.75	1865	25.56	13.15	1.1567	11454	0.7511
13	7	0.3454	90.20	103.80	1900	26.34	13.60	1.1435	11326	0.7306
14	7	0.3454	90.20	103.80	1910	26.49	13.60	1.1430	11322	0.7303
15	8	0.3462	90.20	103.80	1875	26.48	13.60	1.1225	11093	0.7138
16	8	0.3462	90.20	103.80	1875	26.54	13.60	1.1199	11068	0.7122
17	9	0.3448	1.35	19.00	1855	27.27	13.45	1.0783	10700	0.6952

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.35	19.00	1865	27.41	13.45	1.0786	10702	0.6954
19	10	0.3457	1.35	19.00	1790	26.71	13.45	1.0623	10514	0.6813
20	10	0.3457	1.35	19.00	1845	27.41	13.45	1.0670	10560	0.6843
21	11	0.3464	2.70	16.00	1920	25.79	13.30	1.1801	11656	0.7581
22	11	0.3464	2.70	16.00	1885	25.43	13.30	1.1750	11606	0.7548
23	12	0.3456	2.70	16.00	1850	25.02	13.30	1.1721	11603	0.7564
24	12	0.3456	2.70	16.00	1910	25.91	13.30	1.1686	11568	0.7541
25	13	0.3467	59.80	73.10	1900	25.95	13.30	1.1606	11454	0.7443
26	13	0.3467	59.80	73.10	1810	24.79	13.30	1.1574	11422	0.7422
27	14	0.3445	59.80	73.10	1930	26.39	13.30	1.1593	11513	0.7529
28	14	0.3445	59.80	73.10	1860	25.34	13.30	1.1636	11556	0.7557
29	15	0.3452	29.45	42.80	1920	26.21	13.35	1.1612	11509	0.7497
30	15	0.3452	29.45	42.80	1900	25.87	13.35	1.1642	11539	0.7517
31	16	0.3447	29.45	42.80	1940	26.48	13.35	1.1614	11527	0.7520
32	16	0.3447	29.45	42.80	1840	25.35	13.35	1.1506	11420	0.7450
33	17	0.3455	1.40	14.70	1865	25.74	13.30	1.1486	11374	0.7416
34	17	0.3455	1.40	14.70	1880	26.01	13.30	1.1458	11346	0.7398
35	18	0.3449	1.40	14.70	1940	26.66	13.30	1.1535	11443	0.7474
36	18	0.3449	1.40	14.70	1930	26.48	13.30	1.1554	11461	0.7486
AVERAGE							13.28	1.1478	11366	0.7417

TOTAL INFLOW = 20.6607 (GPM)

Note: For holes 9-10 the net head is average of the neighbouring holes (7-8 & 11-12).
The liquid elevation column reads the head shown in the glass tubes which was different from what was actually present.

TABLE A7-20

Run # 23 — **Water Temperature: 75.2 F**
Date: 7/7/93 — **Water Density: 997.296Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.922 cp**
Experimental Condition: Constant Inlet Flow of Water (22.29 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.90	78.85	1950	24.68	15.95	1.2525	12432	0.7419
2	1	0.3447	62.90	78.85	1950	24.59	15.95	1.2571	12477	0.7447
3	2	0.3458	62.90	78.85	1960	24.65	15.95	1.2604	12471	0.7419
4	2	0.3458	62.90	78.85	1990	25.04	15.95	1.2598	12464	0.7415
5	3	0.3457	31.80	47.90	1940	24.48	16.10	1.2562	12433	0.7364
6	3	0.3457	31.80	47.90	1925	24.23	16.10	1.2594	12464	0.7383
7	4	0.3455	31.80	47.90	1885	23.63	16.10	1.2645	12522	0.7421
8	4	0.3455	31.80	47.90	1945	24.37	16.10	1.2652	12528	0.7425
9	5	0.3462	17.60	33.55	1930	23.84	15.95	1.2833	12682	0.7536
10	5	0.3462	17.60	33.55	1935	23.94	15.95	1.2813	12662	0.7524
11	6	0.3455	17.60	33.55	1920	24.05	15.95	1.2655	12532	0.7462
12	6	0.3455	17.60	33.55	1920	24.02	15.95	1.2671	12548	0.7471
13	7	0.3454	90.20	106.60	1920	24.34	16.40	1.2504	12386	0.7275
14	7	0.3454	90.20	106.60	1940	24.55	16.40	1.2527	12408	0.7288
15	8	0.3462	90.20	106.60	1910	24.89	16.40	1.2164	12022	0.7045
16	8	0.3462	90.20	106.60	1880	24.45	16.40	1.2189	12046	0.7059
17	9	0.3448	1.35	21.40	1935	25.70	16.28	1.1935	11843	0.6994

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.35	21.40	1935	25.69	16.28	1.1940	11848	0.6997
19	10	0.3457	1.35	21.40	1830	25.12	16.28	1.1548	11429	0.6732
20	10	0.3457	1.35	21.40	1880	25.75	16.28	1.1573	11454	0.6747
21	11	0.3464	2.70	18.85	1820	22.45	16.15	1.2851	12693	0.7491
22	11	0.3464	2.70	18.85	1860	22.91	16.15	1.2870	12711	0.7502
23	12	0.3456	2.70	18.85	1860	23.19	16.15	1.2714	12587	0.7446
24	12	0.3456	2.70	18.85	1910	23.77	16.15	1.2738	12610	0.7460
25	13	0.3467	59.80	75.95	1880	23.62	16.15	1.2617	12451	0.7342
26	13	0.3467	59.80	75.95	1860	23.35	16.15	1.2627	12461	0.7348
27	14	0.3445	59.80	75.95	1900	23.93	16.15	1.2586	12500	0.7418
28	14	0.3445	59.80	75.95	1820	22.73	16.15	1.2693	12606	0.7481
29	15	0.3452	29.45	45.65	1895	23.81	16.20	1.2616	12504	0.7394
30	15	0.3452	29.45	45.65	1800	22.70	16.20	1.2570	12458	0.7367
31	16	0.3447	29.45	45.65	1860	23.42	16.20	1.2590	12496	0.7400
32	16	0.3447	29.45	45.65	1900	23.86	16.20	1.2623	12529	0.7420
33	17	0.3455	1.40	17.50	1920	24.49	16.10	1.2428	12307	0.7294
34	17	0.3455	1.40	17.50	1910	24.23	16.10	1.2496	12374	0.7334
35	18	0.3449	1.40	17.50	1910	24.20	16.10	1.2511	12411	0.7368
36	18	0.3449	1.40	17.50	1910	24.20	16.10	1.2511	12411	0.7368
AVERAGE							16.14	1.2504	12382	0.7329

TOTAL INFLOW = 22.5073 (GPM)

Note: For holes 9-10 the net head is average of the neighboring holes (7-8 & 11-12).
The liquid elevation column reads the head shown in the glass tubes which was different from what was actually present.

TABLE A7-21

Run # 24 — **Water Temperature: 75.7 F**
Date: 7/8/93 — **Water Density: 997.222Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.916 cp**
Experimental Condition: Constant Inlet Flow of Water (24.11 gpm on Flow Meter)
Inlet at 1.875 in. From Bottom of the Trough

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	62.90	81.70	1920	22.49	18.80	1.3533	13519	0.7384
2	1	0.3447	62.90	81.70	1925	22.54	18.80	1.3538	13524	0.7387
3	2	0.3458	62.90	81.70	1895	22.37	18.80	1.3428	13372	0.7280
4	2	0.3458	62.90	81.70	1980	23.42	18.80	1.3402	13345	0.7266
5	3	0.3457	31.80	50.70	1740	20.43	18.90	1.3501	13448	0.7305
6	3	0.3457	31.80	50.70	1895	22.26	18.90	1.3495	13442	0.7301
7	4	0.3455	31.80	50.70	1905	22.44	18.90	1.3457	13412	0.7289
8	4	0.3455	31.80	50.70	1895	22.77	18.90	1.3193	13149	0.7146
9	5	0.3462	17.60	36.40	1900	21.91	18.80	1.3747	13673	0.7436
10	5	0.3462	17.60	36.40	1935	22.38	18.80	1.3706	13632	0.7414
11	6	0.3455	17.60	36.40	1930	22.45	18.80	1.3628	13582	0.7401
12	6	0.3455	17.60	36.40	1895	22.06	18.80	1.3617	13572	0.7396
13	7	0.3454	90.20	109.50	1890	22.32	19.30	1.3423	13382	0.7199
14	7	0.3454	90.20	109.50	1880	22.15	19.30	1.3455	13414	0.7216
15	8	0.3462	90.20	109.50	1850	22.34	19.30	1.3127	13057	0.7008
16	8	0.3462	90.20	109.50	1895	22.96	19.30	1.3083	13013	0.6985
17	9	0.3448	1.35	24.20	1930	23.41	19.18	1.3069	13052	0.7056

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.35	24.20	1940	23.63	19.18	1.3014	12997	0.7026
19	10	0.3457	1.35	24.20	1700	21.69	19.18	1.2424	12376	0.6673
20	10	0.3457	1.35	24.20	1840	23.45	19.18	1.2438	12390	0.6680
21	11	0.3464	2.70	21.75	1930	22.19	19.05	1.3787	13706	0.7400
22	11	0.3464	2.70	21.75	1970	22.66	19.05	1.3781	13700	0.7397
23	12	0.3456	2.70	21.75	1830	21.11	19.05	1.3742	13692	0.7410
24	12	0.3456	2.70	21.75	1970	22.83	19.05	1.3679	13629	0.7376
25	13	0.3467	59.80	78.80	1940	22.70	19.00	1.3548	13456	0.7268
26	13	0.3467	59.80	78.80	1930	22.52	19.00	1.3585	13493	0.7289
27	14	0.3445	59.80	78.80	2025	23.74	19.00	1.3522	13516	0.7347
28	14	0.3445	59.80	78.80	1880	21.93	19.00	1.3589	13583	0.7384
29	15	0.3452	29.45	48.70	1925	22.46	19.25	1.3586	13553	0.7305
30	15	0.3452	29.45	48.70	2000	23.31	19.25	1.3601	13567	0.7313
31	16	0.3447	29.45	48.70	1870	21.88	19.25	1.3548	13534	0.7305
32	16	0.3447	29.45	48.70	1930	22.71	19.25	1.3472	13458	0.7264
33	17	0.3455	1.40	20.40	1920	22.70	19.00	1.3408	13363	0.7243
34	17	0.3455	1.40	20.40	1940	22.88	19.00	1.3441	13396	0.7261
35	18	0.3449	1.40	20.40	1930	22.71	19.00	1.3472	13450	0.7303
36	18	0.3449	1.40	20.40	1950	22.95	19.00	1.3469	13447	0.7302
AVERAGE							19.03	1.3431	13386	0.7250
						TOTAL INFLOW (GPM)	-	24.1754		

Note: For holes 9-10 the net head is average of the neighboring holes (7-8 & 11-12).
The liquid elevation column reads the head shown in the glass tubes which was different from what was actually present.

TABLE A7-22

Run # 25 — **Water Temperature: 80 F**
Date: 8/25/93 — **Water Density: 996.595Kg / Cu.m.**
Plate Thickness : 11 gage — **Water Viscosity: 0.867 cp**
Experimental Condition: Constant Inlet Flow of Water (6.0 gpm on Flow Meter)
Inlet in a Weir of Height 2.75 in. from the bottom and placed at one end of the trough.

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	-	-	-	-	-	-	-	-
2	1	0.3447	-	-	-	-	-	-	-	-
3	2	0.3458	-	-	-	-	-	-	-	-
4	2	0.3458	-	-	-	-	-	-	-	-
5	3	0.3457	31.8	32.8	1760	55.63	1.00	0.5015	4996	1.1796
6	3	0.3457	31.8	32.8	1810	55.96	1.00	0.5127	5107	1.2060
7	4	0.3455	31.8	32.8	1550	44.17	1.00	0.5563	5544	1.3099
8	4	0.3455	31.8	32.8	1700	47.97	1.00	0.5618	5599	1.3229
9	5	0.3462	17.6	17.8	850	42.09	0.20	0.3201	3184	1.6789
10	5	0.3462	17.6	17.8	980	49.99	0.20	0.3108	3091	1.6297
11	6	0.3455	17.6	17.8	480	33.95	0.20	0.2241	2234	1.1801
12	6	0.3455	17.6	17.8	610	41.15	0.20	0.2350	2342	1.2374
13	7	0.3454	90.3	91.1	1180	47.41	0.80	0.3945	3933	1.0394
14	7	0.3454	90.3	91.1	1175	47.99	0.80	0.3881	3869	1.0225
15	8	0.3462	90.3	91.1	650	36.94	0.80	0.2789	2774	0.7314
16	8	0.3462	90.3	91.1	690	47.41	0.80	0.2307	2295	0.6050
17	9	0.3448	1.7	2.3	900	43.07	0.60	0.3312	3308	1.0111

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.7	2.3	1200	54.94	0.60	0.3462	3458	1.0569
19	10	0.3457	1.7	2.3	960	43.98	0.60	0.3460	3447	1.0507
20	10	0.3457	1.7	2.3	970	46.15	0.60	0.3332	3319	1.0117
21	11	0.3464	2.7	3.4	1020	45.83	0.70	0.3528	3507	0.9878
22	11	0.3464	2.7	3.4	950	38.87	0.70	0.3874	3851	1.0848
23	12	0.3456	2.7	3.4	795	31.87	0.70	0.3954	3940	1.1123
24	12	0.3456	2.7	3.4	920	37.26	0.70	0.3914	3900	1.1010
25	13	0.3467	59.9	60.9	1040	36.95	1.00	0.4462	4431	1.0434
26	13	0.3467	59.9	60.9	1010	36.25	1.00	0.4417	4387	1.0329
27	14	0.3445	59.9	60.9	990	37.22	1.00	0.4216	4215	0.9987
28	14	0.3445	59.9	60.9	990	37.62	1.00	0.4172	4170	0.9881
29	15	0.3452	29.55	30.5	960	37.63	0.95	0.4044	4034	0.9788
30	15	0.3452	29.55	30.5	980	38.7	0.95	0.4014	4004	0.9715
31	16	0.3447	29.55	30.5	870	38.53	0.95	0.3579	3576	0.8688
32	16	0.3447	29.55	30.5	860	38.08	0.95	0.3580	3576	0.8690
33	17	0.3455	1.7	3	1150	39.9	1.30	0.4569	4554	0.9436
34	17	0.3455	1.7	3	1100	38.16	1.30	0.4569	4554	0.9438
35	18	0.3449	1.7	3	1015	37.99	1.30	0.4235	4228	0.8778
36	18	0.3449	1.7	3	1110	41.08	1.30	0.4283	4276	0.8877
AVERAGE							0.82	0.3448	3866	1.0614

TOTAL INFLOW = 6.2062
(GPM)

TABLE A7-23

Run # 26 **Water Temperature: 73.3 F**
Date: 10/2/93 **Water Density: 997.538Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.945 cp**
Experimental Condition: Constant Inlet Flow of Water (13.2 gpm on Flow Meter)
Inlet in a Weir of Height 2.75 in. from the bottom and placed at one end of the trough.

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	-	-	-	-	-	-	-	-
2	1	0.3447	-	-	-	-	-	-	-	-
3	2	0.3458	-	-	-	-	-	-	-	-
4	2	0.3458	-	-	-	-	-	-	-	-
5	3	0.3457	31.85	37.30	1570	30.19	5.45	0.8244	7962	0.8306
6	3	0.3457	31.85	37.30	1575	30.24	5.45	0.8256	7974	0.8319
7	4	0.3455	31.85	37.30	1625	31.27	5.45	0.8238	7961	0.8310
8	4	0.3455	31.85	37.30	1585	30.44	5.45	0.8254	7977	0.8326
9	5	0.3462	17.60	22.95	1550	30.47	5.35	0.8064	7777	0.8177
10	5	0.3462	17.60	22.95	1560	30.86	5.35	0.8013	7728	0.8125
11	6	0.3455	17.60	22.95	1520	30.78	5.35	0.7828	7565	0.7970
12	6	0.3455	17.60	22.95	1535	31.22	5.35	0.7794	7532	0.7935
13	7	0.3454	90.30	95.85	1540	30.38	5.55	0.8036	7768	0.8037
14	7	0.3454	90.30	95.85	1555	30.55	5.55	0.8069	7800	0.8070
15	8	0.3462	90.30	95.85	1580	31.50	5.55	0.7951	7668	0.7916
16	8	0.3462	90.30	95.85	1550	30.90	5.55	0.7952	7669	0.7916
17	9	0.3448	1.70	7.10	1610	31.38	5.40	0.8133	7876	0.8275

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.70	7.10	1570	30.70	5.40	0.8107	7850	0.8249
19	10	0.3457	1.70	7.10	1470	28.84	5.40	0.8080	7804	0.8178
20	10	0.3457	1.70	7.10	1535	30.23	5.40	0.8049	7774	0.8147
21	11	0.3464	2.80	8.35	1600	31.24	5.55	0.8119	7826	0.8073
22	11	0.3464	2.80	8.35	1595	31.10	5.55	0.8130	7836	0.8084
23	12	0.3456	2.80	8.35	1540	30.41	5.55	0.8028	7756	0.8020
24	12	0.3456	2.80	8.35	1540	30.34	5.55	0.8046	7773	0.8038
25	13	0.3467	59.90	65.45	1570	30.61	5.55	0.8131	7830	0.8071
26	13	0.3467	59.90	65.45	1590	30.98	5.55	0.8136	7835	0.8076
27	14	0.3445	59.90	65.45	1555	30.46	5.55	0.8093	7843	0.8136
28	14	0.3445	59.90	65.45	1550	30.38	5.55	0.8088	7839	0.8131
29	15	0.3452	29.55	35.15	1555	30.07	5.60	0.8197	7929	0.8172
30	15	0.3452	29.55	35.15	1570	30.34	5.60	0.8203	7934	0.8177
31	16	0.3447	29.55	35.15	1550	30.24	5.60	0.8125	7870	0.8123
32	16	0.3447	29.55	35.15	1560	30.51	5.60	0.8105	7851	0.8103
33	17	0.3455	1.80	7.40	1565	30.46	5.60	0.8145	7871	0.8105
34	17	0.3455	1.80	7.40	1540	30.25	5.60	0.8070	7799	0.8031
35	18	0.3449	1.80	7.40	1540	30.24	5.60	0.8073	7815	0.8061
36	18	0.3449	1.80	7.40	1550	30.50	5.60	0.8056	7799	0.8044
AVERAGE							5.51	0.8088	7815	0.8116

TOTAL INFLOW = 12.9405 (GPM)

TABLE A7-24

Run # 27 — **Water Temperature: 74.5 F**

Date: 10/3/93 — **Water Density: 997.394Kg / Cu.m.**

Plate Thickness : 11 gage — **Water Viscosity: 0.930 cp**

Experimental Condition: Constant Inlet Flow of Water (18.36 gpm on Flow Meter)
Inlet in a Weir of Height 2.75 in. from the bottom and placed at one end of the trough.

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	-	-	-	-	-	-	-	-
2	1	0.3447	-	-	-	-	-	-	-	-
3	2	0.3458	-	-	-	-	-	-	-	-
4	2	0.3458	-	-	-	-	-	-	-	-
5	3	0.3457	31.80	44.35	1730	24.16	12.55	1.1351	11138	0.7537
6	3	0.3457	31.80	44.35	1800	25.02	12.55	1.1404	11191	0.7572
7	4	0.3455	31.80	44.35	1815	25.12	12.55	1.1454	11245	0.7613
8	4	0.3455	31.80	44.35	1850	25.67	12.55	1.1424	11217	0.7594
9	5	0.3462	17.60	30.15	1700	23.40	12.55	1.1516	11284	0.7624
10	5	0.3462	17.60	30.15	1810	24.80	12.55	1.1569	11336	0.7659
11	6	0.3455	17.60	30.15	1715	23.87	12.55	1.1389	11182	0.7571
12	6	0.3455	17.60	30.15	1720	23.83	12.55	1.1442	11234	0.7606
13	7	0.3454	90.30	103.00	1790	24.73	12.70	1.1474	11269	0.7586
14	7	0.3454	90.30	103.00	1800	24.84	12.70	1.1487	11281	0.7595
15	8	0.3462	90.30	103.00	1800	24.95	12.70	1.1436	11206	0.7526
16	8	0.3462	90.30	103.00	1770	24.44	12.70	1.1480	11249	0.7555
17	9	0.3448	1.70	14.50	1770	24.44	12.80	1.1480	11295	0.7587

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.70	14.50	1780	24.50	12.80	1.1517	11331	0.7611
19	10	0.3457	1.70	14.50	1750	24.04	12.80	1.1540	11323	0.7587
20	10	0.3457	1.70	14.50	1835	25.14	12.80	1.1571	11354	0.7607
21	11	0.3464	2.80	15.65	1770	24.44	12.85	1.1480	11242	0.7503
22	11	0.3464	2.80	15.65	1810	25.04	12.85	1.1459	11221	0.7488
23	12	0.3456	2.80	15.65	1800	24.83	12.85	1.1492	11280	0.7545
24	12	0.3456	2.80	15.65	1795	24.69	12.85	1.1525	11312	0.7566
25	13	0.3467	59.90	72.90	1830	25.49	13.00	1.1381	11135	0.7382
26	13	0.3467	59.90	72.90	1820	25.28	13.00	1.1412	11166	0.7402
27	14	0.3445	59.90	72.90	1770	24.51	13.00	1.1448	11272	0.7520
28	14	0.3445	59.90	72.90	1800	24.94	13.00	1.1441	11266	0.7516
29	15	0.3452	29.55	42.55	1860	25.80	13.00	1.1428	11230	0.7477
30	15	0.3452	29.55	42.55	1840	25.54	13.00	1.1420	11223	0.7472
31	16	0.3447	29.55	42.55	1795	24.98	13.00	1.1391	11210	0.7474
32	16	0.3447	29.55	42.55	1815	25.38	13.00	1.1336	11156	0.7438
33	17	0.3455	1.80	14.80	1810	25.25	13.00	1.1363	11157	0.7422
34	17	0.3455	1.80	14.80	1790	24.90	13.00	1.1396	11189	0.7443
35	18	0.3449	1.80	14.80	1780	24.75	13.00	1.1401	11213	0.7472
36	18	0.3449	1.80	14.80	1780	24.79	13.00	1.1382	11195	0.7460
AVERAGES							12.81	1.1447	11238	0.7532

TOTAL INFLOW = 18.3144 (GPM)

TABLE A7-25

Run # 28 **Water Temperature: 74.3 F**
Date: 10/4/93 **Water Density: 997.419Kg / Cu.m.**
Plate Thickness : 11 gage **Water Viscosity: 0.932 cp**
Experimental Condition: Constant Inlet Flow of Water (21.53 gpm on Flow Meter)
Inlet in a Weir of Height 2.75 in. from the bottom and placed at one end of the trough.

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
1	1	0.3447	-	-	-	-	-	-	-	-
2	1	0.3447	-	-	-	-	-	-	-	-
3	2	0.3458	-	-	-	-	-	-	-	-
4	2	0.3458	-	-	-	-	-	-	-	-
5	3	0.3457	31.80	50.70	1920	22.47	18.90	1.3545	13263	0.7328
6	3	0.3457	31.80	50.70	1880	21.92	18.90	1.3596	13313	0.7356
7	4	0.3455	31.80	50.70	1850	21.50	18.90	1.3640	13364	0.7388
8	4	0.3455	31.80	50.70	1870	21.77	18.90	1.3617	13341	0.7376
9	5	0.3462	17.60	36.60	1875	21.91	19.00	1.3566	13264	0.7299
10	5	0.3462	17.60	36.60	1850	21.61	19.00	1.3571	13269	0.7302
11	6	0.3455	17.60	36.60	1895	22.27	19.00	1.3489	13216	0.7287
12	6	0.3455	17.60	36.60	1840	21.65	19.00	1.3472	13200	0.7278
13	7	0.3454	90.30	109.35	1880	22.05	19.05	1.3516	13246	0.7296
14	7	0.3454	90.30	109.35	1815	22.42	19.05	1.2833	12577	0.6928
15	8	0.3462	90.30	109.35	1850	21.70	19.05	1.3514	13214	0.7262
16	8	0.3462	90.30	109.35	1860	21.87	19.05	1.3482	13182	0.7244
17	9	0.3448	1.70	20.60	1900	22.38	18.90	1.3458	13212	0.7319

READING #	HOLE NUMBER	AVEG. HOLE DIA., IN.	ZERO POINT CM	LIQUID ELEVATION CM	VOLUME COLLECTED ML	TIME SEC	NET HEAD CM	FLOW RATE GPM	REYNOLDS NUMBER	ORIFICE COEFF.
18	9	0.3448	1.70	20.60	1890	22.20	18.90	1.3496	13249	0.7340
19	10	0.3457	1.70	20.60	1880	21.84	18.90	1.3645	13361	0.7383
20	10	0.3457	1.70	20.60	1915	22.29	18.90	1.3619	13335	0.7368
21	11	0.3464	2.80	21.80	1920	22.43	19.00	1.3569	13260	0.7293
22	11	0.3464	2.80	21.80	1900	22.27	19.00	1.3524	13216	0.7269
23	12	0.3456	2.80	21.80	1885	22.08	19.00	1.3533	13255	0.7307
24	12	0.3456	2.80	21.80	1870	21.88	19.00	1.3548	13270	0.7315
25	13	0.3467	59.90	79.10	1890	22.11	19.20	1.3551	13230	0.7232
26	13	0.3467	59.90	79.10	1940	22.75	19.20	1.3518	13198	0.7215
27	14	0.3445	59.90	79.10	1930	22.54	19.20	1.3573	13337	0.7337
28	14	0.3445	59.90	79.10	1885	22.00	19.20	1.3582	13346	0.7342
29	15	0.3452	29.55	48.90	1910	22.21	19.35	1.3632	13368	0.7311
30	15	0.3452	29.55	48.90	1890	22.00	19.35	1.3618	13354	0.7303
31	16	0.3447	29.55	48.90	1895	22.10	19.35	1.3593	13348	0.7310
32	16	0.3447	29.55	48.90	1900	22.19	19.35	1.3573	13329	0.7300
33	17	0.3455	1.80	21.10	1930	22.64	19.30	1.3513	13240	0.7244
34	17	0.3455	1.80	21.10	1960	23.05	19.30	1.3479	13206	0.7225
35	18	0.3449	1.80	21.10	1925	22.60	19.30	1.3502	13252	0.7263
36	18	0.3449	1.80	21.10	1960	22.95	19.30	1.3538	13287	0.7282
AVERAGES							19.09	1.3528	13253	0.7291

TOTAL INFLOW - 21.6453 (GPM)

APPENDIX 8

SAMPLE CALCULATIONS

1) A Priori Prediction of Trough Performance: The distributor parameters are:

Thickness: 11 gage(0.12 in.)

Hole Diameter: 11/32 in. = 0.8731 cm.

Number of Holes: 18 (For runs using the momentum breaker, the effective number of holes will be 16)

An average value of the orifice coefficient was selected to predict the head that develops in the trough for a given flow rate. This was based on the data obtained from single orifice plate tests for 12 gage plates with hole diameters of 0.25 and 0.50 inches for heads ranging from 4cm. to 50 cm. The value thus obtained was 0.78. The flow through each orifice is given by

$$Q_o = v_o A_o$$

where, $v_o = C_o(2gh)^{1/2}$

$$A_o = \pi d_o^2/4$$

Substituting $C_o = 0.78$, $g = 980$ cm/s^2, and $d_o = 0.8731$ cm, we get

$Q_o = 20.676(h)^{1/2}$; h in cm., Q_o in cm^3/s

or

$Q_o = 0.3277(h)^{1/2}$; h in cm, Q_o in gpm.

The total flow rate through all the holes is given by

$Q_T = 18Q_o = 5.899(h)^{1/2}$; h in cm., Q_T in gpm.

i.e. $h = (Q_T)^2/34.8$

Hence, for example if the flow rate is 18.74 gpm(Run# 8), then the predicted head would be $(18.74)^2/34.8 = 10.09$ cm. Calculations for other flow rates can be performed similarly.

APPENDIX 9

ERROR ANALYSIS

The method of Lyon(1970) will be used to determine the error in the derived quantities. This method was also used by Derasari(1992) to quantify the errors in his experiments. According to this method,

$$\text{If } u = Cx^l y^m z^n .....$$

where C is a constant, and l, m, n,... are any real numbers and if the relative error in x, y, z,.. are $\frac{E_x}{X}$, $\frac{E_y}{Y}$, $\frac{E_z}{Z}$,... respectively, then relative error in u, $\frac{E_u}{U}$, can be evaluated as

$$\frac{E_u}{|U|} = \left|l\frac{E_x}{X}\right| + \left|m\frac{E_y}{Y}\right| + \left|n\frac{E_z}{Z}\right| + ... \qquad \text{(A9-1)}$$

The measured quantities are -

Volume of water collected, V(ml)

Time of collection, t(sec)

Liquid elevation or head, h(cm)

Liquid temperature, T(^{o}F)

Diameter of orifice, d(inches)

If E_M is the maximum estimated error for each measured quantity and if M is the maximum value of that quantity, then the relative error for that quantity is E_M/M. Table A9-1 shows the relative errors in the measured quantities

TABLE A9-1

Relative Errors in Measured Quantities

	V, ml	t, sec	h, cm	d, in
E_M	20	0.3	0.3	0.001
M	2000	60	19	0.346
$\%E_M/M$	1	1	1.6	0.3

Since $Re = \frac{dv_o\rho}{\mu}$

$$C_o = \frac{v_o}{\sqrt{2gh}}$$

The relative errors in Re and C_O can be obtained from Eqn. A9-1 as

$$\frac{E_{Re}}{Re} = \frac{E_{v_o}}{v_o} + \frac{E_d}{d} + \frac{E_\rho}{\rho} + \frac{E_\mu}{\mu} \qquad \text{(A9-2)}$$

$$\frac{E_{C_o}}{C_o} = \frac{E_{v_o}}{v_o} + \frac{1}{2}\frac{E_h}{h} \qquad \text{(A9-3)}$$

Also, $v_o = \frac{Q}{A_o}$ and $Q = \frac{V}{t}$ and since the orifice cross-sectional area depends on the square of the orifice diameter, hence we have

$$\frac{E_{v_o}}{v_o} = \frac{E_Q}{Q} + 2\frac{E_d}{d} \qquad \text{(A9-4)}$$

and

$$\frac{E_Q}{Q} = \frac{E_V}{V} + \frac{E_t}{t} \qquad \text{(A9-5)}$$

Considering the maximum relative uncertainty in ρ as 0.2% and μ as 1.5%, Eqns. A9-2, A9-3, A9-4 and A9-5 can be used to find the relative errors in Re and C_O. These are found to be

$$\frac{E_{C_o}}{C_o} = 3.4\%$$

$$\frac{E_{Re}}{Re} = 4.6\%$$

This translates into error bands as shown in Figs. A9-1 & A9-2

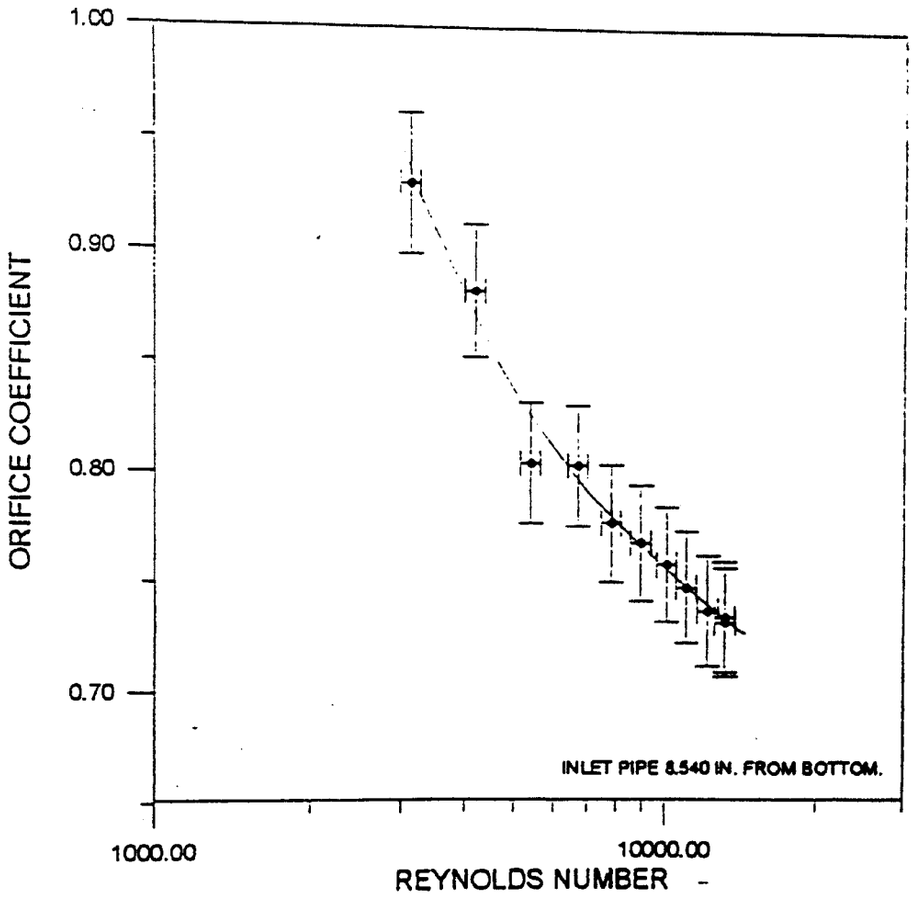

Fig. A9-1 Experimental Error Bands for Co & Re
(Inlet Pipe 8.54 in. from Trough Bottom)

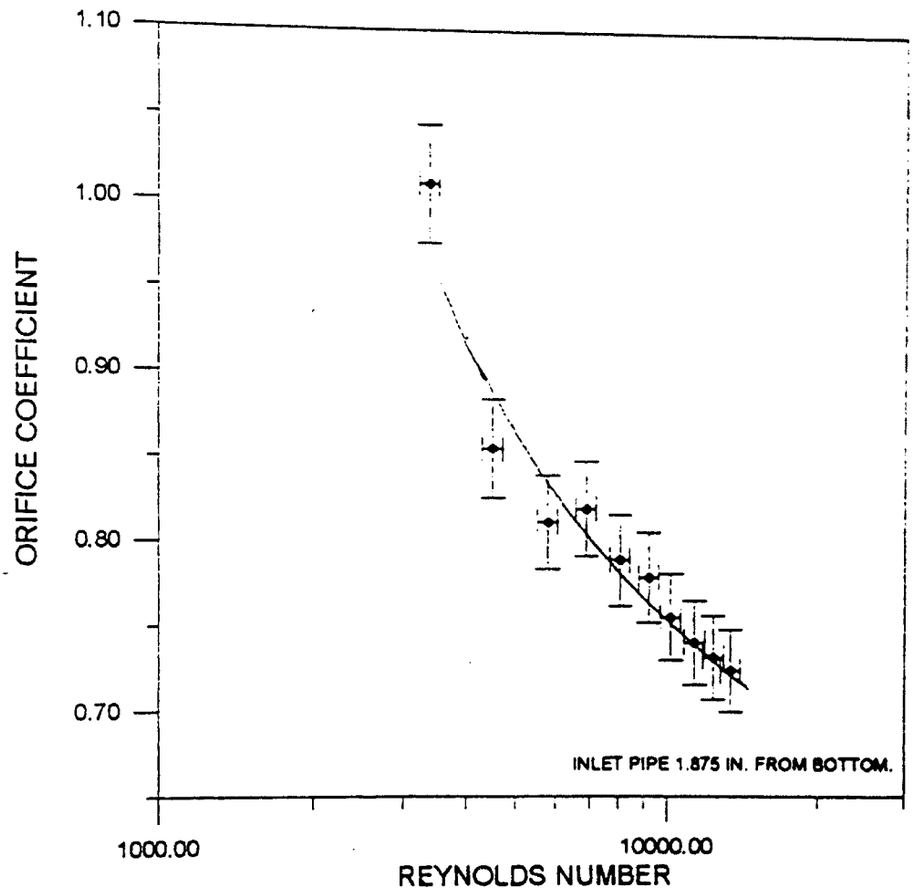

Fig. A9-2 Experimental Error Bands for Co & Re
(Inlet Pipe 1.875 in. from Trough Bottom)

APPENDIX 10

CORRELATION FOR CALCULATING VISCOSITY OF WATER

The viscosity of the water was calculated at the average temperature, using the following correlation. (Reid, Sherwood and Prausnitz, 1977)

$\log_{10}\eta = A' + B'(T-T')$

η = Viscosity of the liquid, cp

T = Temperature, ^{o}K

For water, A' = -1.5668; B'=230.298; T' = 146.797

Temperature Range: -10 to 160 ^{o}C

Percentage Error: 0.51%

VITA

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